One current treatment option for severe mitral valve insufficiency is mitral valve repair. It is performed under cardiopulmonary bypass, similar to human repair for the same condition. Humans have a 90% success rate compared to variable rates in veterinary medicine.\(^1\hspace{1em}3\) One difference between human and canine repair is that annuloplasty rings are usually implanted in humans to reduce the size of the annulus and oppose the mitral leaflets.\(^1\hspace{1em}3\hspace{1em}4\) In veterinary medicine, the surgeon may create an annuloplasty ring freehand with visual estimation and/or partially suture the commissures closed.\(^1\) Although annuloplasty rings help standardize the surgical procedure and prevent stenosis of the mitral valve in humans, they are not easily adapted to veterinary medicine as a result of size and inconsistency among manufacturers.\(^4\) In veterinary medicine, there are no established guidelines for size of the ring or the end resulting diameter needed for mitral valve repair.

We feel that the first step in developing an annuloplasty device for dogs is to measure the mitral annulus in normal dogs across breeds. CT has been used to measure valve sizes and to predict valve replacement and annulus size in humans using both ECG gated and nongated techniques.\(^5\hspace{1em}11\) The purpose of this study was to measure the mitral annulus and report the trigone-to-trigone distance (TTD), remaining circumference, commissure-to-commissure distance, septal leaflet-to-lateral leaflet distance, T4 length, and the total circumference normalized by T4.

The samples included 233 CT scans of dogs without known heart disease. The mean weight was 28.1 kg, with a variety of breeds represented. Golden Retrievers (n = 28) and Labrador Retrievers (n = 37) were overrepresented. The means and SDs of each measurement were as follows: trigone-to-trigone distance, 17.2 ± 4.7 mm; remaining circumference, 79.0 ± 17.5 mm; commissure-to-commissure distance, 30.8 ± 6.5 mm; septal leaflet-to-lateral leaflet distance, 26.3 ± 6.0 mm; T4 length, 16.9 ± 3.1 mm; and the total circumference normalized by T4, 5.7 ± 0.7 mm.

This study provides information that may help in the development of future treatment for mitral valve dysfunction and subsequent annular enlargement.
Materials and Methods

Retrospectively, the postcontrast venous phase thoracic CT scans of dogs with noncardiac clinical disease, acquired using a Toshiba Aquilion 64 CFX 64-detector row CT scanner (Toshiba Medical Systems), were included in the study regardless of diagnostic indication. Scans were excluded if heart disease was diagnosed or suspected based on the presence of a murmur, clinical signs of overload (ie, progressive respiratory rate increases or respiratory distress), CT imaging abnormalities of the heart or great vessels, or if masses caused displacement of the heart. All CT examinations were performed with the patient under general anesthesia with IV fluid support and positioned in sternal or dorsal recumbency.

Additional standard parameters used for CT scans at our institution include a rotation time of 0.5 seconds, a pitch factor of 0.828, 120 kVp, and variable milliamps (20 to 200 mA, calculated by the scanner software [Sure Exposure 3D Version V3.35ER006; Toshiba Medical Systems]). After a noncontrast scan, patients were given 770 mg iodine/kg contrast medium (Optiray 350; Mallinckrodt Inc) followed by a 5-mL saline (0.9% saline) solution, and 3-phase angiography was performed. Arterial phase scans were initiated when the CT density of the aorta at the level of the diaphragm reached 180 HU. Venous and delayed phase images were acquired 15 and 90 seconds after the initiation of the arterial scan, respectively. Postcontrast images in the venous phase with a 0.5- to 1-mm slice thickness were used for reconstruction and measurements (VuePACS version 12.1.6; Carestream Health).

There were 5 investigators trained under the direction of a board-certified radiologist who measured the mitral annulus using multiplanar reformation tools based on previously published techniques. Ten randomly chosen dogs were measured by all 5 observers to determine whether systematic differences exist and to report the interrater variability, and the remaining dogs were allocated randomly to the observer.

Using multiplanar reformation tools, the image was manipulated to show the short-axis view of the mitral valve and the geometric D-shape of the annulus. Measurements were taken, including the TTD, the remaining circumference of the mitral annulus, the CCD, and the SLD (Figure 1). The length of the fourth thoracic vertebra (T4) was measured by manipulating the image to get a midsagittal view of the thoracic spine to allow measurement of the length of the T4 vertebral body.

Statistical analysis

The means and SDs were calculated for the sample population and all measurements. In addition, the total circumference was calculated by adding the TTD to the remaining circumference. The interrater reliability was evaluated using intraclass coefficients for all observers. The total circumference was divided by the T4 length and weight to determine whether standardization was possible, and a regression analysis was performed to provide correlation coefficients for these 2 methods of normalizing to body size. The total circumference was also graphed in 5-kg increments for visualization of the data. In addition, data are reported by breed if > 10 dogs of the breed were available.

Results

There were 233 CT scans eligible for inclusion. Dogs weighed between 2 and 96 kg (mean, 28.1 kg; median, 28.5 kg). Although a variety of breeds were represented, Golden Retrievers (n = 28) and Labrador Retrievers (n = 37) were over represented. Chondrodystrophic breeds based on Packer et al14 included Dachshund (n = 7), Basset Hound (n = 3), Beagle (n = 4), Bichon Frise (n = 1), Cavalier King Charles Spaniel (n = 2), Corgi (n = 1), English Bulldog (n = 2), Cocker Spaniel (n = 4), Jack Russel Terrier (n = 2), Maltese (n = 2), Miniature Poodle (n = 3), Pug (n = 2), and Shih Tzu (n = 1). There were 99 females (6 intact) and 134 males (11 intact). There was no difference in any measurement by sex. The intraclass correlations for all observers’ measurements were > 0.9, showing excellent agreement among observers (TTD, 0.91; remaining circumference, 0.96; CCD, 0.98; SLD, 0.95; and T4, 0.97).

Figure 1—CT scans of the mitral valve annulus in a normal dog presented in a soft tissue window. A—Representative oblique dorsal planar reformed image of the mitral valve annulus; cranial is to the top of the image, and the patient’s right side is on the left of the image. Sagittal plane reformatted image (B) and transverse plane image (C) used to adjust the reformatting plane as depicted in (A). The oblique red lines represent the reformatting plane used in (A). D, E—Mitral valve annulus measurements acquired in all subjects. The black dots represent the locations of each trigone. CCD = Commissure-to-commissure distance. RC = Remainder of the circumference of the mitral valve annulus. SLD = Septal leaflet-to-lateral leaflet distance. TTD = Trigone-to-trigone distance.
The means and SDs of each measurement are presented in Table 1 for all dogs, Golden Retrievers, Labrador Retrievers, chondrodystrophic dogs, and small dogs by weight. The mean ± SD of the total circumference was 96.2 ± 2 mm. The total circumference normalized by the length of T4 was 5.7 ± 0.7 with an $r^2$ value of 0.6. The total circumference normalized by weight was 4.4 ± 2.2 mm/kg with an $r^2$ value of 0.5. The data normalized to T4 were normal, whereas the data normalized to weight were skewed. The total annular measurement is presented in 5-kg increments in Figure 2 for all dogs. The distribution and pattern were similar for all measurements when grouped by weight.

### Table 1—Mean and SD for mitral annular measurements by category.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>TTD (mm)</th>
<th>RC (mm)</th>
<th>CCD (mm)</th>
<th>SLD (mm)</th>
<th>T4 length (mm)</th>
<th>Normalized to T4 length&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>All dogs</td>
<td>233</td>
<td>17.2 ± 4.7</td>
<td>79.0 ± 17.5</td>
<td>30.8 ± 6.5</td>
<td>26.3 ± 6.0</td>
<td>16.9 ± 3.1</td>
<td>5.7 ± 0.7</td>
</tr>
<tr>
<td>Chondrodystrophic breeds</td>
<td>34</td>
<td>13.2 ± 4.1</td>
<td>60.6 ± 13.9</td>
<td>24.1 ± 15.3</td>
<td>19.8 ± 4.7</td>
<td>13.0 ± 1.9</td>
<td>5.7 ± 0.8</td>
</tr>
<tr>
<td>Labrador Retriever</td>
<td>37</td>
<td>19.7 ± 3.5</td>
<td>87.4 ± 11.0</td>
<td>35.2 ± 4.0</td>
<td>28.9 ± 4.2</td>
<td>17.8 ± 1.3</td>
<td>6.0 ± 0.6</td>
</tr>
<tr>
<td>Golden Retriever</td>
<td>28</td>
<td>17.9 ± 3.5</td>
<td>86.0 ± 13.6</td>
<td>33.0 ± 3.9</td>
<td>28.8 ± 4.6</td>
<td>18.2 ± 0.8</td>
<td>5.7 ± 0.8</td>
</tr>
<tr>
<td>Dogs &lt; 5 kg</td>
<td>5</td>
<td>8.72 ± 4.0</td>
<td>46.7 ± 10.1</td>
<td>18.4 ± 3.7</td>
<td>15.2 ± 3.7</td>
<td>9.9 ± 1.4</td>
<td>5.6 ± 0.7</td>
</tr>
<tr>
<td>Dogs 5–9 kg</td>
<td>26</td>
<td>11.2 ± 2.6</td>
<td>54.4 ± 8.4</td>
<td>21.2 ± 3.5</td>
<td>17.6 ± 2.7</td>
<td>11.9 ± 1.3</td>
<td>5.5 ± 0.8</td>
</tr>
<tr>
<td>Dogs 10–14 kg</td>
<td>15</td>
<td>14.3 ± 3.6</td>
<td>62.0 ± 8.7</td>
<td>24.8 ± 3.0</td>
<td>20.3 ± 2.8</td>
<td>13.2 ± 1.1</td>
<td>5.8 ± 0.6</td>
</tr>
</tbody>
</table>

CCD = Commissure-to-commissure distance. RC = Remainder of the circumference of the mitral valve annulus. SLD = Septal leaflet-to-lateral leaflet distance. T4 = thoracic vertebrae 4. TTD = Trigone-to-trigone distance.<br>

<sup>a</sup> Total annular circumference divided by the length of T4.

**Discussion**

This study reports the measurements of the mitral valve in a population of dogs using CT multiplanar reformation tools. Because the mitral valve is 3-D and saddle shaped, it may be argued that using a 2-D measurement technique may be an oversimplification of the anatomy. Although this may be true, multiple human studies have shown this measurement technique to be adequate for mitral annular sizing.<sup>6,7,12,13</sup> The ideal study would have included a postmortem measurement of the annulus to determine the accuracy of our measurements.

The variation in annular size likely has many contributing factors, including interobserver variability, normal anatomic variation, subclinical heart disease, and measurement error resulting from motion and reconstruction artifacts. It is unlikely that those performing the measurements added much to the variation. All observers were trained as a group to optimize the view of the mitral annulus, limiting interobserver variation and maximizing agreement. Although this is a subjective process and can be difficult, agreement was excellent using this strategy. Others<sup>6</sup> have reported excellent agreement in CT annular measurements as well.

Anatomic variation includes different breeds and sizes of dogs. It is reasonable to expect a 2-kg Chihuahua to have a different-size heart overall than a 96-kg Mastiff. The variation decreases considerably when normalized to size using the length of T4. This is depicted by the difference in measurements in Labrador Retrievers and chondrodystrophic breeds that washes out when the length of T4 is used to standardize it (Table 1). However, this is not an ideal standardization method, because only 60% of the variation in mitral circumference can be attributed to size as it relates to the length of T4. Weight was less advantageous, with only 50% of the variation attributable to variation in weight. If all dogs were at ideal body condition, it is possible that correlation would be better. In humans, body surface area is used to standardize valve sizes, but in this study, the information to calculate body surface area was not available.

In addition, it is unknown whether other factors affect mitral valve size and shape, such as athletic breeds or those with different conformations. Chest width is used to index heart size in humans. Actual width may not be appropriate to standardize different
Dog confirmations, but a similar measurement such as thoracic inlet diameter may prove to be a better standardizing measurement in future studies.15

Dogs have been used as models for human cardiovascular research because of similar-size hearts.14 The commissural distance in humans has been reported to be 33.4 ± 2.3 mm, which is similar to our study. Another study17 reported annular circumference in diastole as 123 ± 9 mm and systole as 109 ± 10 mm. This is similar to the Retrievers in our study in both measurement and variation. It is possible that studies presenting measurements with very low variation are examining homogeneous populations. There is evidence that variation may be greater when people are studied across world populations.18

In our study, dogs were excluded if a heart murmur was auscultated, heart disease was diagnosed previously, or the CT scan showed evidence of a heart abnormality. This includes routine evaluation of great vessels for evidence of fluid overload or deficiency. All of these are screening techniques and subjective. The gold standard for determining normal dogs is ECG evaluation. Therefore, some dogs with heart disease or disease contributing to significant blood volume changes may be contributing to the variation seen in this population.

The CT and associated software used in this study are designed to limit motion artifacts, but this does not negate the fact that the scans were not ECG gated. The mitral valve changes in size and shape from diastole to systole and some variation may be dependent on the phase when measured, which may be averaged by the software.6,17 It is possible that if heart motion had been eliminated as a factor, measurements would have been more accurate and possibly less variable. In humans, mitral valves have been imaged with more advanced equipment that is ECG gated and measured with software that allows 3-D mapping in all phases of contraction.6,7,12,17 In our study, this technology was not available and the methods were designed for the equipment that is available. Although more precise information is always preferred, full annuloplasty rings do not allow changes in annular size during diastole or systole, so it is possible that more precise measurement is not necessary for creating an annular ring, especially if D shaped.10,12,13

This study describes normal values for multiple mitral valve measurements using CT reconstruction. Our results provide valuable information for developing surgical and catheter-based treatments for mitral disease in the future.

Acknowledgments

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References