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VERTEBRAL SCALE SYSTEM TO MEASURE HEART SIZE IN RADIOGRAPHS

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Differences in chest conformation among dog breeds previously limited the use of measurement to ascertain cardiac enlargement. Studies using planimetry and a variety of cardiothoracic ratios have been reported, but these methods have not proved suitable for general clinical use.[8, 9, 18, 19, 25, 26, 28] A guideline of 2.5 to 3.5 intercostal spaces for deep- or wide-chested dogs, respectively, was introduced 32 years ago[4] and is still used by some radiologists and cardiologists as an indicator of normal heart size in lateral radiographs.[10, 16] Limitations of this method include variations in the axis of the heart, chest conformation, phase of respiration, superimposition of ribs, and imprecise measurement points.

To overcome these limitations, a variety of alternative heart:skeletal ratios were explored to identify a method that would be anatomically justifiable, reasonably precise, repeatable, and simple to use and explain. Emphasis was placed on comparisons of heart size and vertebral length, because both features are present in thoracic radiographs, and good correlations are known to exist between heart weight and body length.[22]

The method described in this article satisfied the desired criteria of consistency, precision, and simplicity, and data are presented to show its application. Cardiac dimensions were compared with the length of midthoracic vertebrae and sternebrae in 100 dogs and 100 cats with normal hearts and various chest conformations.[6, 13] The objectives of the studies were to (1) standardize a useful new method for cardiac mensuration; (2) determine values for relative heart size in normal

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dogs and cats using this method; (3) determine the influences of chest conformation, gender, body size, and right versus left lateral positioning on the measurement system in dogs; and (4) demonstrate the use of the vertebral heart size (VHS) method to evaluate progressive cardiomegaly in dogs with heart disease. Recent textbooks have included descriptions of the VHS method for evaluation of heart size.[14, 17]

CASE MATERIAL

Recumbent lateral and ventrodorsal (VD) or dorsoventral (DV) radiographs of 100 dogs without clinical evidence of cardiac or pulmonary disease were selected from current case material. Heart sizes were considered to be normal by radiologists or cardiologists on duty. Included were VD radiographs of 79 dogs and DV radiographs of 21 dogs. All dogs were mature and ranged in weight from 2 to 75 kg. There were 43 male dogs, 52 female dogs, and 5 dogs of unknown gender. No more than 4 dogs of any one breed were included. For most dogs, left lateral recumbent radiographs were available, but for 20 animals, both right and left lateral recumbent radiographs had been made to rule out metastatic lung disease before surgical removal of nonthoracic tumors. Both lateral views were measured in this group of dogs to assess the influence of right versus left recumbency on heart size:vertebra correlations. Two dogs with increasingly severe mitral regurgitation were also evaluated to illustrate VHS change in progressive cardiomegaly. Normal thoracic radiographs of 100 adult cats of varying ages, breeds, and sizes in a hospital population also were measured. Included were recumbent lateral radiographs of 100 cats, VD radiographs of 93 cats, and DV radiographs of 27 cats. Data are expressed as the mean ± standard deviation (SD).

MEASUREMENT METHODS

In lateral radiographs of dogs, the cardiac long axis was measured from the ventral border of the left mainstem bronchus to the most distant ventral contour of the cardiac apex (Fig. 1). This dimension reflects the combined size of the left atrium and left ventricle (Fig. 2). The measurement was made using an adjustable caliper, which was then repositioned over thoracic vertebrae beginning with the cranial edge of the fourth thoracic vertebra (T4). The distance to the caudal caliper point was estimated to the nearest 0.1 vertebra. The caliper was then placed on a metric ruler, and the interval was recorded to the nearest millimeter to obtain more precise measurements for statistical analysis. Measurement of the cardiac long axis in cats differed slightly, because the heart usually lies more parallel to the sternum. The base of the heart is at the intersection of the ventral edge of the trachea and the most ventral apical pulmonary vein just cranial to the tracheal bifurcation. In dogs with a large left atrium and elevated left bronchus caudal to the tracheal

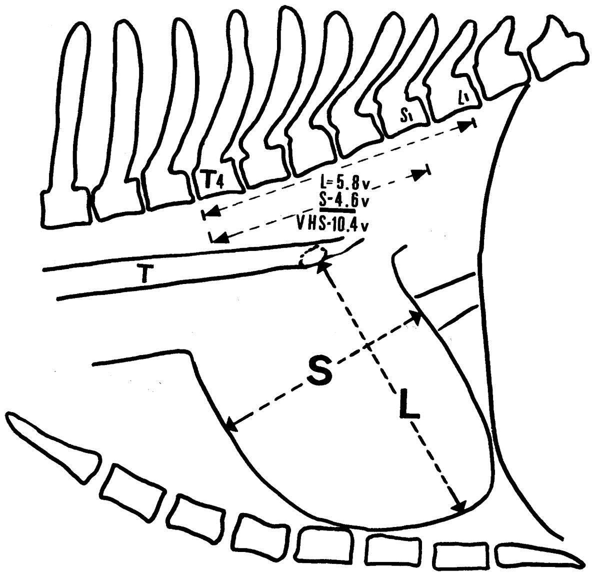

Figure 1. Lateral diagram illustrating the vertebral heart size (VHS) measurement method. The long axis (L) and short axis (S) heart dimensions are transposed onto the vertebral column and recorded as the number of vertebrae beginning with the cranial edge of the fourth thoracic vertebra (T4). These values are then added to obtain the vertebral heart size. T = trachea. (*From* Buchanan JW, Bücheler J: Vertebral scale system to measure canine heart size in radiographs. JAVMA 206:194–199, 1995; with permission.)

bifurcation, the long axis measurement is made from the ventral edge of the elevated left bronchus to the apex of the heart (Fig. 3). This measurement reflects the increase in the long axis dimensions in dogs with left heart enlargement.

The maximal short axis of the heart in the central third region perpendicular to the long axis was also measured beginning with T4. The short and long axis dimensions were then added to yield a vertebrae:heart sum as an indicator of heart size in relation to body length. The overall size of the heart was thus expressed as total units of vertebral length to the nearest 0.1 vertebra and termed the *vertebral heart size*. In DV and VD radiographs, the maximal long and short axes of the heart were determined with calipers in a similar fashion and measured against vertebrae in the lateral radiograph beginning with T4 (Fig. 4). The maximal diameter of the caudal vena cava (CVC) was measured in lateral radiographs and compared with the length of the single vertebra dorsal to the tracheal bifurcation (usually T5). A 10-vertebrae long index of body length was made by doubling the length of five vertebrae from the cranial edge of T4 to the caudal edge of T8.

An alternative to using calipers in daily clinical work consists of placing a sheet of paper over the heart with one corner of the paper at

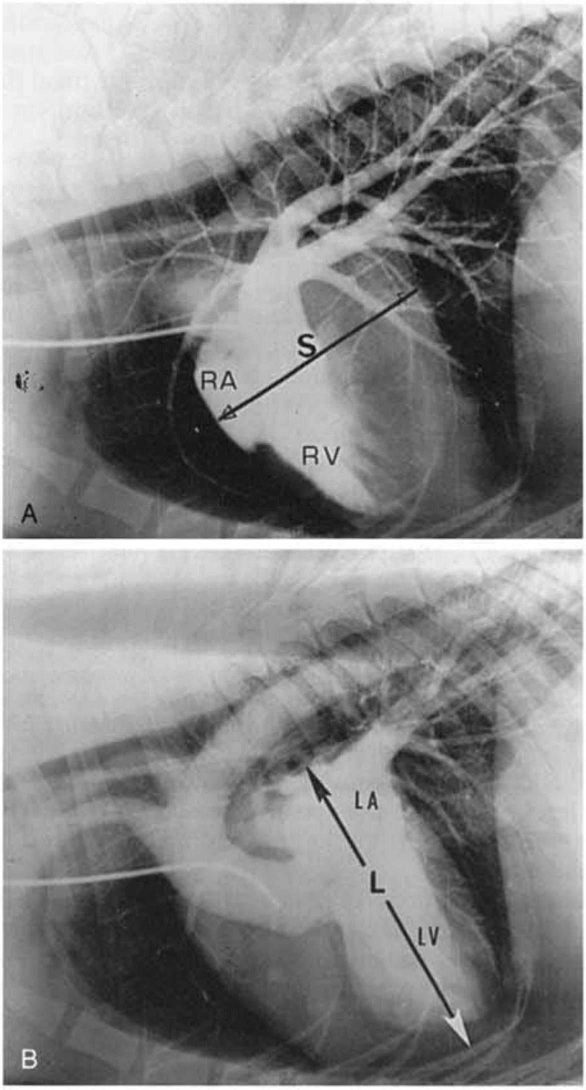

Figure 2. Lateral angiocardiograms of a normal 6-year-old Collie. *A*, In the dextrophase, notice that the short axis dimension (S) includes both left and right heart chambers in the region of the coronary groove. RA = right atrial appendage; RV = right ventricle. *B*, In the levophase, notice that the long axis measurement (L) from the left main stem bronchus to the cardiac apex represents the combined size of the left atrium (LA) and left ventricle (LV). (*From* Buchanan JW, Bücheler J: Vertebral scale system to measure canine heart size in radiographs. JAVMA 206:194–199, 1995; with permission.)

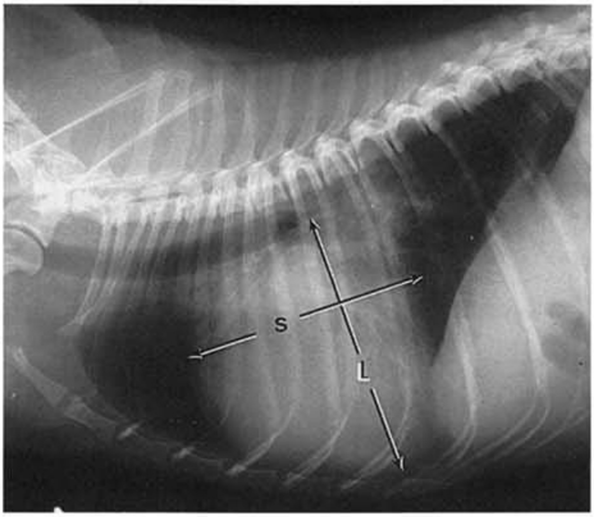

Figure 3. Recumbent left lateral radiograph of a 7-year-old Cavalier King Charles Spaniel with severe mitral regurgitation and marked, progressive cardiomegaly (VHS 13.3v) (see also Fig. 8). The long axis (L) is measured from the cardiac apex to the elevated left bronchus in order to include left atrial enlargement. The short axis (s) is measured at the level of the dorsal border of the caudal vena cava also to reflect left atrial enlargement.

the base of the heart. The paper is marked at the apex to indicate the long axis and then repositioned perpendicular to the long axis. The same corner is placed at the cranial edge of the heart, and the caudal border is marked to indicate the short axis. The corner of the paper is then placed at the cranial edge of T4, and the long and short axes are recorded as the number of vertebrae between the corner and the marked axes.

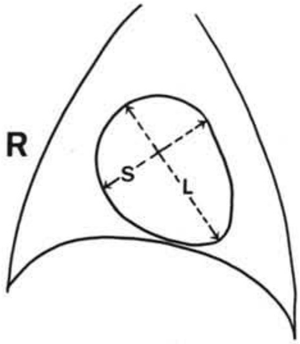

Figure 4. Dorsoventral diagram illustrating the short (S) and long (L) axis dimensions of the heart that were measured in VD and DV radiographs. (*From* Buchanan JW, Bücheler J: Vertebral scale system to measure canine heart size in radiographs. JAVMA 206:194–199, 1995; with permission.)

These values are then added to yield the VHS. In dogs with marked left atrial enlargement, the short axis measurement is made at the level of the dorsal border of the CVC to reflect the increase in volume associated with left atrial enlargement (see Fig. 3).

Depth:width ratios of the thorax were determined in 100 normal dogs to obtain an expression of breed conformational differences. The depth of the thorax was measured in lateral radiographs from the cranial edge of the xiphoid process to the ventral border of the vertebral column along a line perpendicular to the vertebral column. Thoracic width was measured in DV or VD radiographs as the distance between the medial borders of the eighth ribs at their most lateral curvatures. Deep-chested dogs (11 dogs) were defined as those with depth:width ratios of 1.25 or greater. Broad-chested dogs (11 dogs) were defined as those with depth:width ratios of 0.75 or less.

RESULTS

Lateral Radiographs

The VHS in 100 normal dogs was 9.7 vertebrae ± 0.5 (SD). The range of 8.5 to 10.6 vertebrae had a normal distribution (Fig. 5). Both the long and short axis dimensions were significantly correlated with

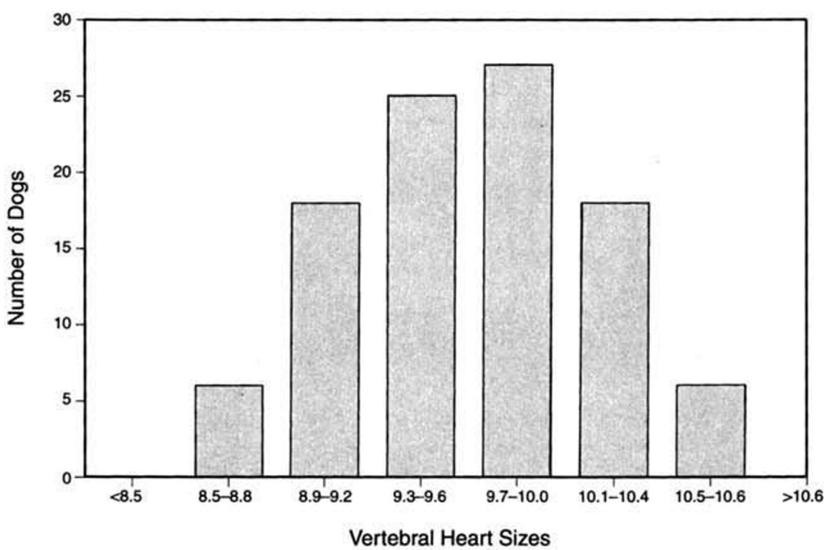

Figure 5. Distribution of vertebral heart sizes in 100 normal dogs. (*From* Buchanan JW, Bücheler J: Vertebral scale system to measure canine heart size in radiographs. JAVMA 206:194–199, 1995; with permission.)

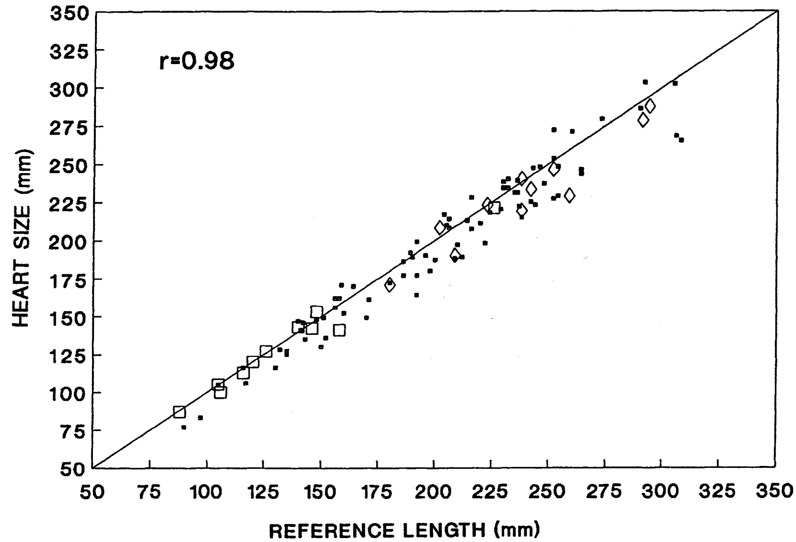

Figure 6. Correlation between the sum of long- and short-axis heart dimensions and the 10 vertebrae reference length in 100 normal dogs of various body types. Broad-chested, small dogs are indicated by open squares. Deep-chested, large dogs are indicated with diamond-shaped symbols. The straight line represents the line of identity between heart size and the 10 vertebrae reference length. (*From* Buchanan JW, Bücheler J: Vertebral scale system to measure canine heart size in radiographs. JAVMA 206:194–199, 1995; with permission.)

the 10-vertebrae reference length ($r = 0.92$ and $r = 0.94$, respectively; $P<0.0001$), but the sum had a higher correlation coefficient ($r = 0.98$; $P<0.0001$) (Fig. 6). In 100 normal cats, the average VHS was 7.5 vertebrae ± 0.3.

Thoracic size and depth:width ratios had no influence on the correlation between heart size and vertebral length. The relationship between VHS and the 10-vertebrae reference length was linear and essentially identical in deep-, intermediate-, and broad-chested dogs (see Fig. 6). Eleven deep-chested dogs in which the chest depth was more than 1.25 times the chest width had a relatively large long axis and a small short axis, but the sum of the two (9.54 vertebrae ± 0.34) was not significantly different from that in wide-chested dogs, where the VHS was 9.76 vertebrae ± 0.33 ($P>0.05$). Dogs with intermediate depth:width ratios from 1.25 to 0.75 (n=78) had an average VHS of 9.64 vertebrae ± 0.54.

Gender and right versus left lateral recumbency did not significantly influence heart size. Of 20 dogs in which both right and left lateral radiographs were available, the heart sizes were essentially equal in 6 dogs. In 10 dogs, the VHS in the right lateral projection was 0.2 to 0.5 vertebra larger than in the left projection. In 4 dogs, the VHS in the left lateral projection was 0.4 vertebra larger than in the right projection. The lengths of five vertebrae (T4–T8) measured in both right and left lateral projections of 20 dogs were essentially equal (±1%).

Good correlations also were observed between heart size and the length of three or four sternebrae (r = 0.94 and r = 0.95, respectively; $P<0.0001$). These values were slightly less than those of vertebral correlations and yielded no advantage over vertebral correlations, except in dogs with hemivertebrae or other vertebral abnormalities.

The CVC diameter correlated moderately with the maximal length of the fifth or sixth thoracic vertebra (r = 0.78). The average CVC: vertebra ratio was 0.75 vertebra ± 0.13. Three dogs had a CVC diameter essentially equal to that of T5 or T6, whereas the CVC was smaller than either of these vertebrae in the 97 other dogs; thus, the length of the vertebra over the tracheal bifurcation is proposed as a clinically useful upper normal limit for the diameter of the CVC. In cats, the CVC was relatively smaller than in dogs when compared with T5 (0.6 vertebra ± 0.09).[13]

Ventrodorsal and Dorsoventral Radiographs

Dimensions of the heart in VD or DV radiographs of dogs were more variable than in lateral radiographs. In 79 VD radiographs, the mean VHS was 10.2 vertebrae (± 0.83). In 21 DV radiographs, the mean VHS was 10.2 vertebrae (± 1.45). The mean long axis dimension in VD or DV radiographs was 11.9% (± 13.8) longer than in lateral radiographs. The mean short axis dimension was slightly but not significantly narrower than in lateral radiographs (0.7% ± 8.6). There were noticeable differences between measurements of VD and DV radiographs of the same animals. A comparison of measurements in 17 dogs in which both VD and DV radiographs were available showed that hearts in the VD projection were 7.2% (± 4.5) wider and 5.3% (± 3.2) longer than in the DV projection. Because of the variability in VD and DV dimensions and the fact that most radiographs available for analysis in this study were VD films, detailed correlation analysis of body length versus VD or DV heart size in dogs was not performed.

In cats, clinical experience has shown that left atrial enlargement is the earliest and most frequent radiographic change in animals with heart disease. This is best seen in VD radiographs in cats; thus, correlations were made between the VD short axis dimension (which extends through the left atrium) and the length of vertebrae beginning with T4 in the lateral radiograph. The normal short axis dimension in VD radiographs of 93 cats was 3.4 vertebrae (± 0.25).[13]

Progressive cardiomegaly in radiographs and echocardiograms of a dog with mitral regurgitation showed that the VHS increased steadily over a 3.5-year period from 10.9 to 13.2 vertebrae (21% increase; Fig. 7). In echocardiograms, the left atrial dimension increased from 2.5 to 3.3 cm (28%), whereas the aortic dimension decreased slightly. Consequently, the standard left atrium:aorta ratio showed the greatest change

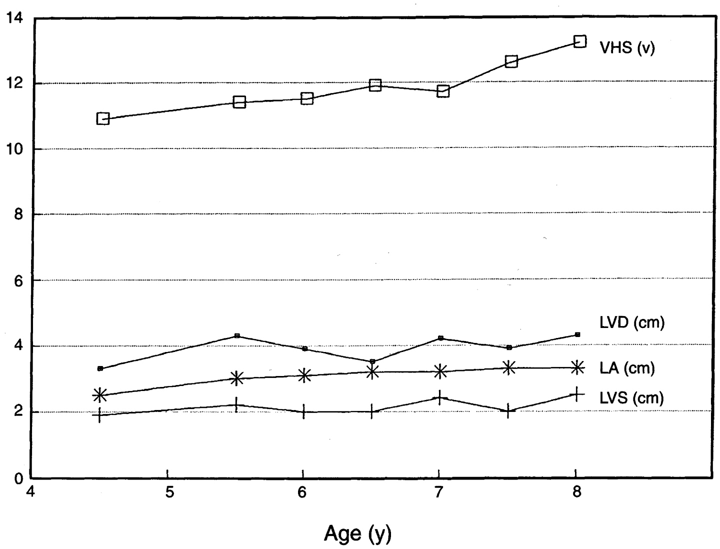

Figure 7. Radiographic and echocardiographic measurements in a dog with mitral regurgitation and progressive cardiomegaly from 4.5 to 8 years of age. The progressive increase in heart size was more apparent in radiographic measurements using the VHS method than M-mode echocardiographic measurements of individual cardiac chambers. LVD = left ventricular chamber in diastole; LVS = left ventricular chamber in systole; LA = left atrial dimension. (*From* Buchanan JW, Bücheler J: Vertebral scale system to measure canine heart size in radiographs. JAVMA 206:194–199, 1995; with permission.)

over the 3.5-year period, increasing from 1.5 to 2.2 (47%). Echocardiographic left ventricular dimensions did not increase over the final 2.5 years, whereas the VHS increased from 11.4 to 13.2 vertebrae (16%) during the same period. In another dog with more rapidly progressive cardiomegaly (see Fig. 3), the VHS increased from 10.9 to 13.9 vertebrae (28%) over a 2-year period (Fig. 8). The increase in VHS was caused by increases in both the long and short axes and was accompanied by similar increased dimensions of the thorax (see Fig. 8). Echocardiograms in this dog revealed the same percentage of increase in the left ventricular dimensions as that of the increase in VHS during the 2-year period that radiographs were available (Fig. 9). Echocardiography 8 months before radiography revealed smaller left heart chambers and indicated that significant left ventricular enlargement already had occurred at the time of initial radiography. Aortic diameter decreased when the dog was in severe intractable heart failure; thus, the left atrium:aortic ratio was greatly increased (see Fig. 9). Mitral regurgitant ejection time and aortic ejection time decreased during the 2 years of progressive cardiomegaly (Fig. 10).

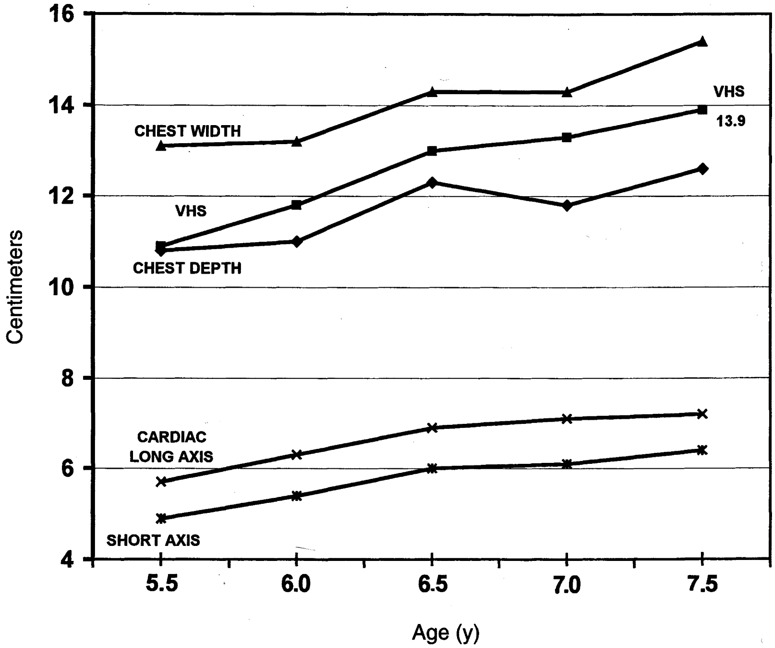

Figure 8. Parallel increase in cardiac and thoracic dimensions in radiographs of a dog with progressive cardiomegaly from 5.5 to 7.5 years of age. The cardiothoracic ratio did not change significantly even though the heart became very large (radiograph at 7 years of age is shown in Fig. 3).

DISCUSSION

Cardiac mensuration is helpful for inexperienced observers as a starting point in evaluating heart size. It is less important for experienced viewers, who can usually recognize cardiomegaly empirically. Even in this instance, measurement may be useful in questionable cases. Most notable has been the assessment of heart size in normal dogs with a wide or barrel-chested thorax. In lateral radiographs of such animals, the heart occupies more of the chest depth than usual, and the trachea seems to be elevated. VHS measurement consistently reveals a normal value for heart size in lateral radiograph, however, and the heart is typically normal in DV or VD projections. Many animals with this chest conformation and no heart disease have been referred for cardiac evaluation because of misdiagnosed cardiomegaly.

The VHS was equal to or less than 10.5 vertebrae in 98% of the dogs in this study, and this value is suggested as a clinically useful upper limit for normal heart size in most breeds. Exceptions may occur in dogs with a short thorax such as the Miniature Schnauzer, in which a VHS up to 11 vertebrae is probably normal. Conversely, an upper limit

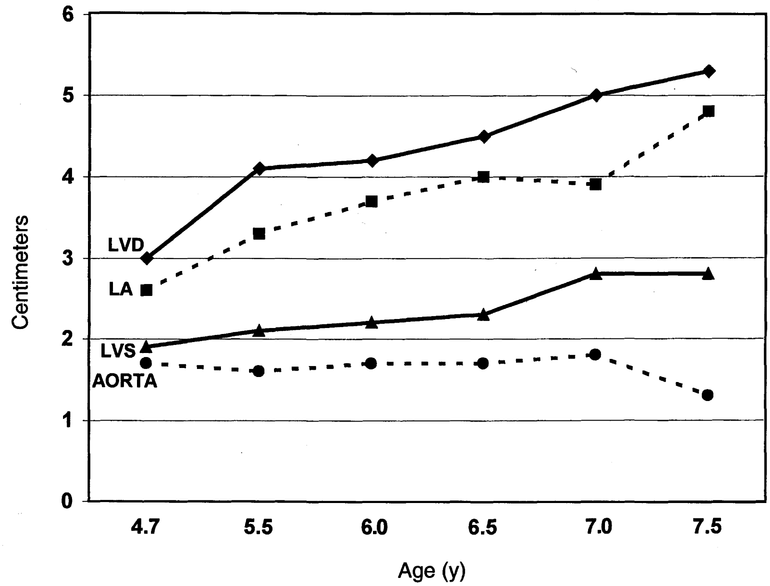

Figure 9. Dimensional changes in echocardiograms of the dog with progressive cardiomegaly whose radiographic measurements are presented in Figure 8. Notice the significant increase in left atrial size and reduction in aortic diameter at 7.5 years. Both changes contribute to a marked increase in the left atrium/aortic ratio.

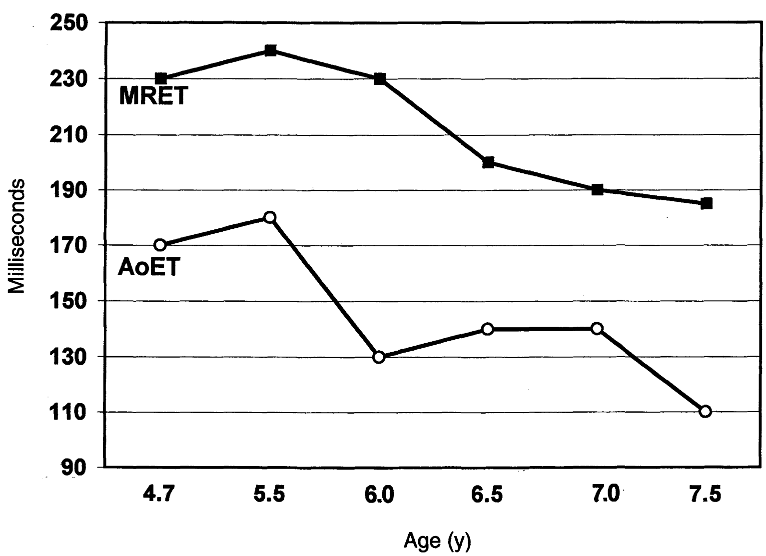

Figure 10. Decreased mitral regurgitation (MR) and aortic (Ao) ejection times (ET) in the dog with progressive cardiomegaly shown in Figures 3, 8, and 9.

of 9.5 vertebrae may be more appropriate in dogs with a long thorax such as the Dachshund and other breeds with relatively elongated body types. Studies in larger numbers of dogs of each breed are required to determine more precise values for individual breeds. Radiographs of growing dogs showed no significant differences in relative heart size. The average VHS measurements in 11 normal puppies at 3, 6, and 12 months of age were 10.1, 9.9, and 10.0 vertebrae, respectively.[21] In kittens, VHS measurements were above normal at 3 months of age but fell to within the normal range at 6 and 12 months of age.[7]

In addition to initial assessment of heart size, the VHS method is also useful in monitoring the progression of heart enlargement over time.[1, 5] Recording the heart size using a vertebral scale encourages objectivity and is a convenient way of recording changes in heart size in response to treatment or progression of cardiomegaly. Radiographic studies in dystrophin-deficient cats with cardiomyopathy confirmed that the VHS method was a sensitive tool to quantitate progressive cardiomegaly.[7] The example of radiographic and echocardiographic measurements in a dog with progressive cardiomegaly shown in Figure 7 demonstrates that absolute M-mode echocardiographic measurements did not reflect the extent of the heart size increase as well as the VHS method over the final 2.5-year period. This may be because the echocardiographic measurements represent only a single dimension (mainly that of the short axis), whereas the VHS method measures change in two dimensions. In another dog with progressive cardiomegaly, increases in both the long and short axes were observed (see Fig. 8), but similar increases occurred in the M-mode echocardiographic dimensions (see Fig. 9).

The major uses of the VHS method are in helping to determine the presence or absence of cardiomegaly in borderline cases and in quantification of the progression of cardiomegaly over time in a given case. Because the short axis measurement includes both right and left heart chambers, it is increased with either right or left heart enlargement and does not distinguish between right- and left-sided disease. Such distinction usually can be made by analysis of individual chamber contours in lateral and DV or VD radiographs. Using the vertebral scale system, cardiac enlargement was found in 30% of dogs with heartworm disease, and the CVC was enlarged in 14% of the dogs.[11] In another report, Miniature Dachshunds with immunoincompetence and *Pneumocystis carinii* pneumonia had VHS values within the published normal limits, but the smallest VHS values were found in the dogs with the least affected lungs.[12] It is likely that the normal upper limit for VHS in Miniature Dachshunds is somewhat smaller than 10.6 vertebrae, and some of the dogs may in fact have had cardiomegaly.

Reduced heart size based on cardiothoracic ratios has been reported in dogs with experimentally induced adrenal insufficiency.[18] More recently, radiographs of dogs with naturally occurring hypoadrenocorticism were evaluated using the vertebral scale system. The mean VHS in 22 dogs with hypoadrenocorticism (9.2 vertebrae ± 0.5) was significantly less than the mean VHS (10.5 vertebrae ± 0.7) in 22 breed- and weight-matched control dogs.[15] The dogs with hypoadrenocorticism also had smaller pulmonary arteries and smaller CVCs in comparison to control dogs.

DV radiographs are preferred over VD radiographs for the evaluation of heart size in dogs, because cardiac contours are more consistent in DV projections and because there is magnification in VD radiographs as a result of the increased distance between the heart and the cassette. In 100 dogs, the mean long axis dimension in VD or DV radiographs was 11.9% larger than in lateral radiographs. In addition to magnification, the increased length may also reflect the fact that the VD or DV long axis extends through the right atrium and left ventricle, whereas it only includes the left atrium and left ventricle in lateral projections.

The similarity of 10-vertebrae reference lengths in right and left lateral radiographs of 20 dogs was expected and demonstrates the advantage of using central vertebrae instead of intercostal spacing as a reference structure for comparison with heart size as well as other organ dimensions. The similarity of heart sizes in right versus left projections in most dogs in the present study indicates that one projection has no advantage over the other. It is recommended, however, that one projection or the other be used consistently in a given animal so that subtle changes can be detected. The minor differences that were noted in some of the dogs can occur with different phases of the cardiac and respiratory cycles.[20, 24]

It is important to note that normal heart size does not rule out heart disease. Significant hypertrophy may be present without an increase in external heart size. The cardiac silhouette always must be examined for the subtle changes in contour that may occur in hearts with concentric hypertrophy without dilatation. These animals also may have other radiographic changes such as a prominent aortic arch, enlarged or decreased main pulmonary artery size, and altered pulmonary vascularity. Additional heart diseases without notable changes in cardiac size include some aortic and pulmonic stenoses as well as small shunting defects (ventricular and atrial septal defects), including pink tetralogies, endocarditis, acute myocardial failure, arrhythmias, constrictive pericarditis, myocardial neoplasia and cardiac-sensitive metabolic diseases.[23]

The concept of using cardiac:skeletal ratios to assess heart size is not new. Cardiothoracic ratios (width of heart versus width of thorax) in human beings were relied on extensively before the advent of echocardiography and other more sophisticated diagnostic methods. In dogs, however, differences in chest conformation between breeds make standard human type cardiothoracic ratios of little value. Even in the same animal, standard ratios are unreliable to assess sequential changes in heart size. As an example, comparisons of pre- and postoperative radiographs of dogs with patent ductus arteriosus and large hearts consistently show an obvious reduction in heart size after surgery, but the width and depth of the thorax also decrease because of decreased respiratory effort.[2, 3] In addition, the midpoint of the cardiac silhouette, where standard ratios are determined, is displaced cranially into a narrower region of the thorax because of the reduction in left heart chamber size that occurs after patent ductus arteriosus closure. Consequently, there may be no substantial change in cardiothoracic ratios even when there has been an obvious reduction in heart size.

The opposite change in thoracic dimensions has been observed in dogs with a progressive increase in heart size. An example of this is seen in Figure 8, which illustrates increasing thoracic dimensions over a 2-year period in a dog with progressive mitral regurgitation and increasing VHS. The simultaneous increase in VHS and thoracic size minimizes the change in cardiothoracic ratio, because the numerator and denominator are both increased.

The original concept of comparing heart size with intercostal spacing was based on clinical experience and was not evaluated statistically.[4] More recent studies in cats have confirmed the usefulness of comparing heart size with intercostal spaces. In normal cats, the craniocaudal width of the heart does not exceed the distance between the cranial border of the fifth rib and the caudal border of the seventh rib at the midpoint of the ribs.[27] This value is similar to that obtained in our VHS study in 100 cats in which the short axis of the heart was equal to 3.2 vertebrae (± 0.18).[13]

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