Vertebral scale system to measure heart size in radiographs of cats

Annette L. Litster, BVSc, MACVSc, and James W. Buchanan, DVM, MMedSci, DACVIM

Objective—To determine absolute and relative heart size in clinically normal cats by correlating heart size and selected skeletal structures.

Design— Prospective radiographic study.

Animals—100 cats that did not have thoracic radiographic abnormalities.

Procedure—Standardized measurements of the long and short axes of the heart, midthoracic vertebrae, and other structures were made. Measurements were recorded in millimeters and number of thoracic vertebral lengths spanned by each dimension, measured caudally from T4 in a lateral radiograph. The long- and short-axis measurements of the heart, expressed in vertebral lengths, were added to yield vertebral heart size.

Results—Mean ± SD vertebral heart size in lateral radiographs was 7.5 ± 0.3 vertebrae. The long-axis dimension correlated with the length of 3 sternebrae, measured from S2 to S4. The cardiac short-axis dimension correlated moderately with the length of 3.2 vertebrae, measured from T4 to T6. The cardiac short-axis dimension in ventrodorsal radiographs was 3.4 ± 0.25 vertebrae.

Conclusions and Clinical Relevance—The vertebral heart-size method is easy to use, allows objective assessment of heart size, and may be helpful in determining cardiomegaly and comparing heart size in sequential radiographs. (*J Am Vet Med Assoc* 2000;216:210–214)

Determination of heart size is important in evaluating patients with heart disease, because an enlarged cardiac silhouette in radiographs is a reliable indication of pathologic cardiac changes.[1] Other studies have recorded various measurements of the cardiac silhouette in clinically normal cats[2-4] and reported the effects of positioning,[5] age,[6] and cardiac cycle phase.[7] Cardiac measurements also have been related mathematically to the dimensions of other structures on thoracic radiographs.[1,8] Cardiac cycle phase was found to have minimal effect on heart size,[7] and age of subject did not affect cardiac dimensions.[6] Carlisle and Thrall[5] reported that **dorsoventral (DV)** and **ventrodorsal (VD)** views were satisfactory, and any differences in the appearance of the cardiac silhouette in the 2 views were minimal. Van den Broek and Darke[8] related cardiac size to intercostal space measurements. A vertebral scale system for measuring radiographic heart size was reported recently and has proven useful for recording heart size in dogs and quantifying change on subsequent radiographs.[1] The method compares cardiac dimensions to the length of thoracic vertebrae, which are an indication of body size. In lateral radiographs of 100 clinically normal dogs, the sum of measurements of the long and short axes of the heart yielded mean ± SD **vertebral heart size (VHS)** of 9.7 ± 0.5 **vertebrae (v)**. Application of the VHS method in cats in a preliminary study yielded smaller values than in dogs, because cats have relatively longer thoracic vertebrae.

The objectives of the study reported here were to determine absolute and relative heart size in clinically normal cats by correlating heart size and selected skeletal structures. Specifically, our objectives were to determine the dimensions of the cardiac silhouette in thoracic radiographs of clinically normal cats, using standardized measurements, relate cardiac measurements to the length of midthoracic vertebral bodies and establish a VHS reference range, determine whether other skeletal structures correlate with heart size as well as or better than the vertebral scale system, and measure the diameter of the caudal vena cava and relate it to the length of the vertebral body of T4 on the lateral view.

From the Department of Clinical Studies, School of Veterinary Medicine, University of Pennsylvania, Philadelphia, PA 19104. Dr. Litster's present address is the Department of Veterinary Science and Animal Production, University of Queensland, St Lucia, Queensland 4072, Australia.

The authors thank Drs. Rick Atwell, David Knight, Jim Litster, Dan Ohad, Mark Saunders, Meg Sleeper, and Fe Wright, and Cheryl Dougherty, Carla Garcia, and Lee Waldron for technical assistance.

Address correspondence to Dr. Buchanan.

Materials and Methods

Cats and radiography—Thoracic radiographs from 100 adult cats that did not have radiographic abnormalities were assessed by a cardiologist and a radiologist and then measured. Cats were of various ages, breeds, and sizes. Sixty-nine of these cats were referred to the cardiology unit for evaluation prior to surgery, or because they had clinical signs (eg, heart murmur) that may have been consistent with cardiovascular abnormalities. For all cats in this group, abnormalities were not detected by echocardiographic evaluation and thoracic radiography performed on the same day. The remaining 31 cats had radiographic assessment only; evaluation by a radiologist and cardiologist did not reveal abnormalities.

Anesthesia was not used for radiography or echocardiography, and all cats were positioned accurately. Radiographs were taken at full inspiration, if possible, with source-to-image distance of 40 in (100 cm). Radiographic views included recumbent left lateral (n = 100), DV (27), and VD (93) positions. The DV and VD projections were available in 20 cats.

Radiographic measurements—Measurements were made, using adjustable calipers. In the lateral view (**Fig 1**), measurements were made of: 1) length (mm) of 3 vertebrae (from the cranial border of T4 to the caudal border of T6); 2) length (mm) of 3 sternebrae (from the cranial border of the second sternebra to the caudal border of the fourth sternebra; the manubrium was excluded from measurement because of variability in its length); 3) cardiac long axis (from the car-

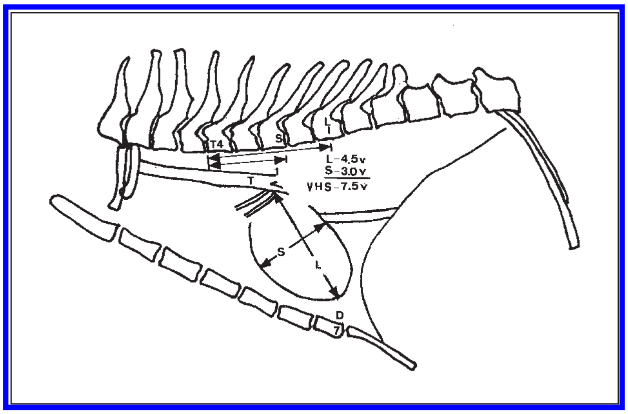

Figure 1—Diagram of lateral view of the thorax of a cat illustrating the vertebral heart size method. The long-axis (L) and short-axis (S) dimensions of the heart are transposed onto the vertebral column and recorded as the corresponding number of vertebrae (v), as measured caudally from the cranial edge of T4. These values are added to obtain the vertebral heart size (VHS). The depth of the thorax (D) is measured from the dorsocaudal border of the 7th sternebra to the closest edge of the vertebral column. T = Trachea.

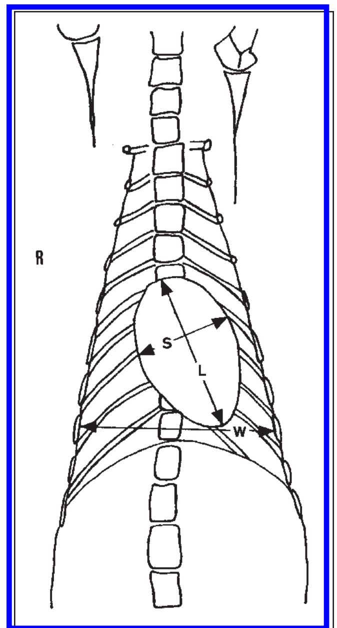

Figure 3—Diagram of the ventrodorsal view of the thorax of a cat, illustrating the L and S dimensions of the heart, which were measured in ventrodorsal and dorsoventral radiographs. The width of the thorax (W) is the distance between the pleural surfaces of the eighth ribs.

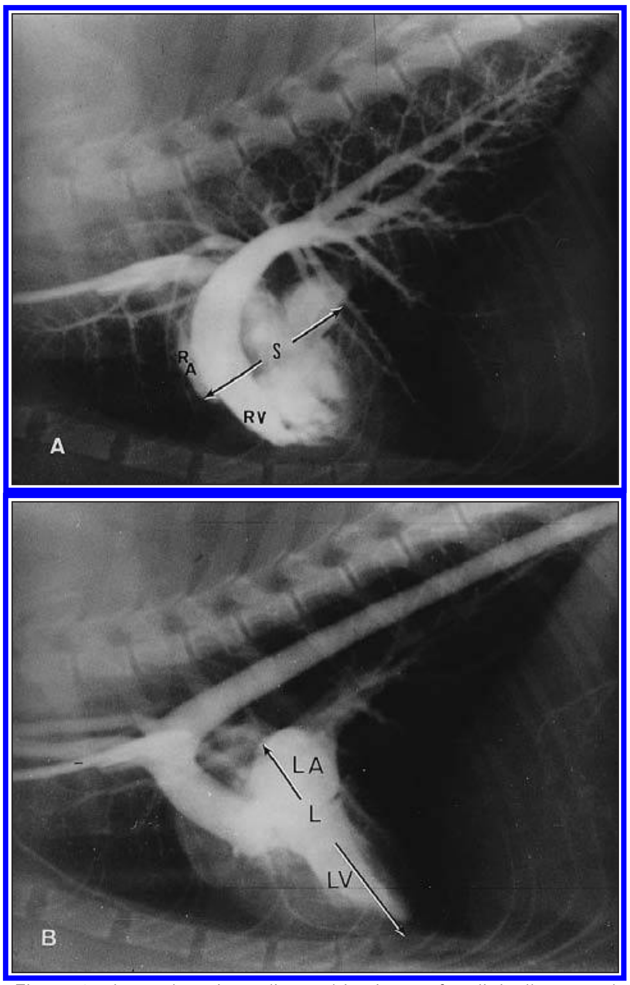

Figure 2—Lateral angiocardiographic views of a clinically normal cat. (A) Dextrophase. Notice that the cardiac S dimension includes left and right heart chambers in the region of the coronary groove. RA = Right atrial appendage. RV = Right ventricle. (B) Levophase. Notice that the L dimension from the trachea to the cardiac apex represents the combined size of the left atrium (LA) and left ventricle (LV).

diac apex to the base of the heart where it intersected the tracheal bifurcation. The base of the heart is at the intersection of the ventral edge of the trachea and the most ventral [right] apical vein, just cranial to the tracheal bifurcation. This dimension reflected the combined size of the left atrium and the left ventricle **[Fig 2]**. The measurement was made using an adjustable caliper that was repositioned over thoracic vertebrae, beginning with the cranial edge of T4. The distance to the caudal caliper point was estimated to the nearest 0.1 v. Measurements that ended within an intervertebral space were counted as having ended at the caudal edge of the last vertebra. The caliper was placed on a metric ruler, and the interval recorded to the nearest millimeter); 4) cardiac short axis (perpendicular to the long axis measurement, at the point of maximum cardiac width, commonly the point at which the cardiac silhouette intersected the ventral border of the caudal vena cava [measured in mm and v]); 5) lateral heart sum (sum of long and short axis measurements); 6) caudal vena cava diameter (measured in mm and v, perpendicular to its length, at the point of intersection with the cardiac silhouette); 7) thorax depth (measured in mm from the caudodorsal aspect of the 7th sternebra to the closest point on the ventral aspect of the thoracic vertebrae, determined by anchoring 1 end of the calipers to the dorsocaudal edge of the 7th sternebra, then sweeping the other end of the calipers in arcs until the shortest distance between the sternum and the ventral thoracic vertebrae was established).

In VD and DV views **(Fig 3)**, measurements were made of thoracic width (mm; the maximum distance between the right and left pleural surfaces of rib 8; cardiac long axis (distance from cardiac apex to base, measured in mm and v, beginning with T4 in the lateral radiograph), cardiac short axis (perpendicular to the long-axis measurement at the maximum cardiac width, measured in mm, and v, beginning with T4 in the lateral radiograph), and VD or DV heart sum (sum of the long- and short-axis measurements, in mm and v). Cardiac measurements with the lowest coefficient of variation were correlated with skeletal structures to identify clinically useful guidelines.

Statistical analyses—For all measurements, mean, SD, and coefficients of variation were determined. Normality of distribution of data on VHS frequency and VD cardiac short-axis frequency expressed graphically was based on visual inspection of the graphs. Linear regression analyses (Pearson correlation coefficient [*r*]) on correlations between the following measurements were determined: lateral view axis sum (mm) versus T4 to T6 (mm), lateral view cardiac short axis (mm) versus T4 to T6 (mm), and lateral view cardiac long axis (mm) versus sternebrae 2 to 4 (mm). For each cat, paired *t*-tests were used to determine differences between means of VD thoracic width and DV thoracic width and means of VHS on the VD view and VHS on the DV view. Differences were considered significant at $P < 0.05$.

Results

Lateral radiographs—Mean VHS for all cats (sum of the cardiac long and short axes; **Fig 4**) was 7.5 ± 0.3 v (range, 6.7 to 8.1 v); this measurement had a normal distribution and the lowest coefficient of variation of all measurements taken in the study (**Table 1**). Cardiac long- and short-axis measurements also had low coefficients of variation. The lateral view axis sum correlated with T4 to T6 length ($r = 0.78$; $P < 0.001$; **Fig 5**).

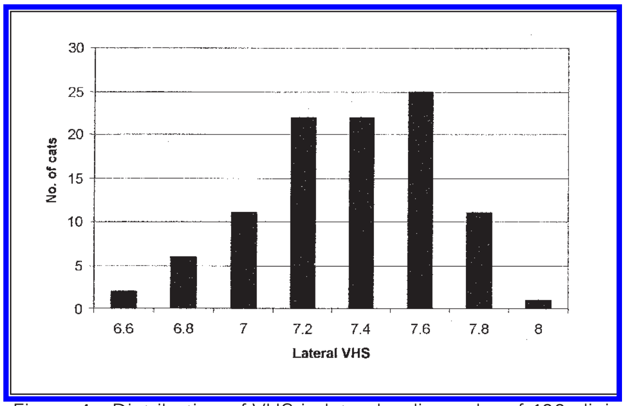

Figure 4—Distribution of VHS in lateral radiographs of 100 clinically normal cats.

Table 1—Thoracic and cardiovascular measurements of 100 clinically normal cats

Measurement	Mean	SD	No. of cats	Coefficient of variation
T4 – T6 (mm)	33.7	2.29	100	0.068
Sternebrae 2 – 4 (mm)	52.1	3.81	87	0.073
Thoracic depth (mm)	70.2	8.07	100	0.115
Caudal vena cava (mm)	6.3	0.97	100	0.154
Caudal vena cava (v)	0.6	0.09	100	0.145
Lateral long axis (mm)	50.0	4.19	100	0.084
Lateral long axis (v)	4.3	0.23	100	0.053
Lateral short axis (mm)	36.0	2.68	100	0.074
Lateral short axis (v)	3.2	0.18	100	0.057
Lateral sum (mm)	86.0	5.91	100	0.069
Lateral sum (v)	7.5	0.30	100	0.040
DV long axis (mm)	55.1	4.94	27	0.090
DV long axis (v)	4.7	0.31	27	0.065
DV short axis (mm)	38.8	2.86	27	0.074
DV short axis (v)	3.4	0.23	27	0.068
DV sum (mm)	93.9	6.94	27	0.074
DV sum (v)	8.1	0.45	27	0.055
DV thoracic width (mm)	82.7	9.60	27	0.116
VD thoracic width (mm)	85.6	9.39	93	0.110
VD long axis (mm)	55.5	4.52	93	0.081
VD long axis (v)	4.8	0.28	93	0.059
VD short axis (mm)	39.3	3.51	93	0.089
VD short axis (v)	3.4	0.25	93	0.073
VD sum (mm)	94.7	7.18	93	0.076
VD sum (v)	8.2	0.43	93	0.052

v = Length measured in vertebrae. DV = Dorsoventral. VD = Ventrodorsal.

There was similarity and moderate correlation between the cardiac short-axis measurement (mean, 36.0 mm) and the T4 to T6 measurement (mean, 33.7 mm; $r = 0.63$; $P < 0.001$; **Fig 6**). The cardiac long-axis measurement (mean, 50.0 mm) correlated moderately with the sternebrae measurement (mean, 52.1 mm; $r = 0.67$; $P < 0.001$; **Fig 7**). The caudal vena cava measurements (mean, 6.3 mm and 0.6 v) had the highest coefficients

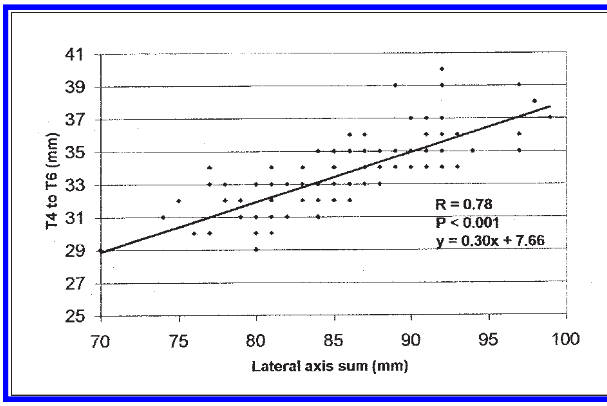

Figure 5—Correlation between the 3-vertebrae reference length (T4 to T6 [mm]) and the sum of the long- and short-axis measurements (mm) on lateral radiographs of 100 clinically normal cats. The straight line represents the line of best fit between T4 to T6 length and cardiac axis sums.

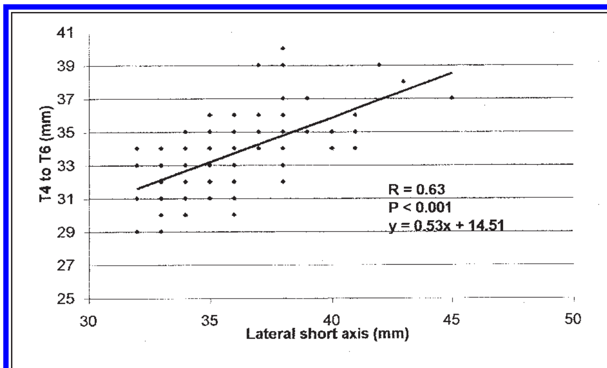

Figure 6—Correlation between T4 to T6 length (mm) and the cardiac short-axis measurement (mm) in lateral radiographs of 100 clinically normal cats. The straight line represents the line of best fit between T4 to T6 length and cardiac short axis.

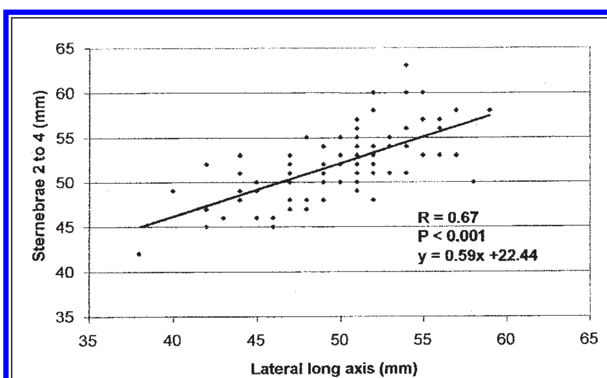

Figure 7—Correlation between the 3-sternebrae reference length (S2 to S4 [mm]) and the cardiac long-axis measurements (mm) in lateral radiographs of 100 clinically normal cats. The straight line represents the line of best fit between S2 to S4 length and lateral cardiac long axis.

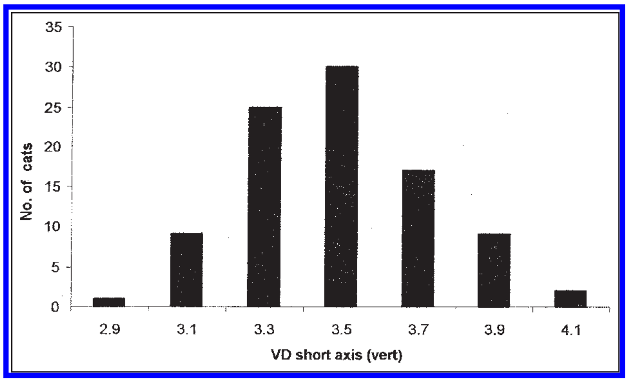

Figure 8—Distribution of cardiac short-axis dimensions (vertebral scale) in ventrodorsal (VD) radiographs of 93 clinically normal cats. The VD cardiac short-axis dimension was scaled in vertebrae (vert) in lateral radiographs, beginning with the cranial border of T4.

of variation. In each instance, measurements expressed in v had lower coefficient of variation than the same measurement expressed in mm.

The VD and DV radiographs—Of all measurements taken, VHS on each of these views had the lowest coefficients of variation. Mean VHS on the VD view was 8.2 ± 0.43 v, whereas on the DV view mean VHS was 8.1 ± 0.45 v; difference between views was not significant. Cardiac short-axis measurements in each view were equal (3.4 v), but the silhouette in the DV view was often blurred in cats with some degree of obesity. The VD cardiac short-axis measurements were normally distributed **(Fig 8)**. Thoracic width on the VD view (mean, 85.6 mm) was slightly larger than on the DV view (mean, 82.7 mm), but the difference was not significant. Thoracic width and depth measurements had high coefficients of variation; therefore, correlations with heart size were not meaningful.

Discussion

Descriptions of the cardiac silhouette of clinically normal cats in standard textbooks are mostly subjective.[9-13] Several authors have cautioned against reliance on measurements of heart size, because such measurements do not take overall body size into account. The purpose of the study reported here was to determine a simple method that compared heart size to skeletal structures in a manner that took overall body size into account and was independent of other factors, such as source-to-image distance. In the study reported here, good correlation between heart size (lateral axis sum) and vertebral length was evident on lateral radiographs; therefore, an index of vertebral length was selected as an indicator of body size.

Although subjective assessment to rule out cardiomegaly or cause suspicion that a cardiac silhouette is abnormal may be sufficiently accurate for an experienced radiologist or cardiologist, a less-experienced clinician can use the VHS method. The VHS measurement also aids in objectively evaluating the progression of radiographic changes.

Cardiomegaly is reliable evidence of heart disease, and its degree may be used to judge severity of disease.[11] However, it should be emphasized that lack of cardiomegaly does not rule out heart disease.[1] For example, cardiomegaly may not be detected radiographically during the early stages of hypertrophic cardiomyopathy, despite its characteristic concentric hypertrophy. Cardiomegaly may also be absent in endocarditis, myocarditis, toxic cardiomyopathy, cardiac contusion, severe arrhythmias, and constrictive pericarditis.[11] Pericardial effusion enlarges the cardiac silhouette and, therefore, influences the interpretation of VHS, but may not necessarily be associated with cardiomegaly.

The vertebral scale system relates cardiac measurements to a skeletal feature that is not altered by cardiorespiratory changes associated with physiologic events or pathologic changes. Van den Broek and Darke[8] reported that a cardiac short-axis measurement exceeding the distance from the cranial border of rib 5 to the caudal border of rib 7 on a lateral radiograph was a highly reliable indicator of cardiomegaly. However, use of this measurement may be limited, because it is affected by phase of the respiratory cycle at the time of exposure and magnification of the upper versus the lower intercostal spaces in lateral views. It also can be affected by changes in thoracic volume during dyspnea. It has been reported that changes in respiratory effort can alter cardiothoracic ratios, even in the same animal.[14] Because the vertebral column is centrally located in the body, its dimensions are not changed by right or left lateral positioning.

Other studies have made some of the measurements used in the study reported here[2-4] and obtained similar results. Measurements made in previous studies in cats have been in millimeters, whereas 1 of the main objectives of our study was to relate cardiac measurements to vertebral length. Measurements (mm) made by Hamlin et al[2] appear to be approximately 10 to 20% smaller than those reported by Lord and Zontine[3] and those made in our study, which may be explained by the fact that Hamlin et al[2] included kittens as young as 6 months of age.

The VHS method is suited to objective assessment of heart size in cats, because cats have relatively uniform thoracic shapes, compared with dogs.[3,11,12] Although dogs of various breeds have much greater diversity in thoracic depth to width ratios than cats of various breeds, a correlation plot between canine heart size (mm) and a 10-vertebrae reference length (mm) did not reveal differences between broad-, medium-, or deep-chested dogs, and the data clustered tightly around a diagonal line of best fit.[1] For our study, a similar correlation plot (Fig 5) appeared to have more scatter, because the cats had a much narrower range of heart sizes and vertebral lengths; the scatter was equivalent to the amount of scatter in a small section of the correlation plot for dogs.

For VD and DV views, differences between dimensions of the cardiac silhouette and thoracic width in a subgroup of cats were not significant. We prefer the VD view over the DV view, because the borders of the cardiac silhouette in the DV view were sometimes obscured by fat in cats that were overweight. Sternal flattening is a factor in the DV view[5] and probably causes displacement of pericardial fat. However, reports of subjective assessments have suggested that the appearance of the heart is more consistent on the DV view.[5]

In older cats, the heart has increased sternal contact on the lateral view,[6] so the cardiac axes may be slightly rotated counterclockwise. In these cats, the caudal short-axis measurement point is less likely to intersect the ventral border of the caudal vena cava, and the cranial short-axis measurement point is at the sternum. Care should also be taken when making the long-axis measurement in cats with increased cardiac sternal contact, because the measurement point at the cardiac base may be more ventral than in younger cats. The right apical vein may help determine the measurement point in these cases.

Results of the study reported here suggest that the most clinically useful vertebral scale guidelines for radiographs of clinically normal cats are: mean VHS in lateral radiographs, 7.5 v (upper limit, 8.0 v); mean cardiac short axis in lateral radiographs, 3.2 v (upper limit, 3.5 v); and mean cardiac short axis in VD or DV radiographs, 3.4 v (upper limit, 4 v). The cardiac long axis in the lateral view approximates the length of 3 sternebrae, measured from S2 to S4.

References

1. Buchanan JW, Bücheler JB. Vertebral scale system to measure canine heart size in radiographs. *J Am Vet Med Assoc* 1995;206: 194–199.
2. Hamlin RL, Smetzer DL, Smith CR. Radiographic anatomy of the normal cat heart. *J Am Vet Med Assoc* 1963;143:957–961.
3. Lord PF, Zontine WJ. Radiologic examination of the feline cardiovascular system. *Vet Clin North Am Small Anim Pract* 1977;7: 291–308.
4. Schafer M, Berry CR. Cardiac and pulmonary artery mensuration in feline heartworm disease. *Vet Radiol Ultrasound* 1995;36: 499–505.
5. Carlisle CH, Thrall DE. A comparison of normal feline thoracic radiographs made in dorsal versus ventral recumbency. *Vet Radiol* 1982;23:3–9.
6. Moon ML, Keene BW, Lessard P, et al. Age related changes in the feline cardiac silhouette. *Vet Radiol Ultrasound* 1993;34: 315–320.
7. Toal RL, Losonsky JM, Coulter DB, et al. Influence of cardiac cycle on the radiographic appearance of the feline heart. *Vet Radiol* 1985;26:63–69.
8. Van Den Broek AHM, Darke PGG. Cardiac measurements on thoracic radiographs of cats. *J Small Anim Pract* 1987;28: 125–135.
9. Root CR, Bahr RJ. The heart and great vessels. In: Thrall DE, ed. *Textbook of veterinary diagnostic radiology*. Philadelphia: WB Saunders Co, 1998;35–336.
10. Bonagura JD. Cardiac imaging. In: Sherding R, ed. *The cat: diseases and clinical management*. Philadelphia: WB Saunders Co, 1994;826–837.
11. Farrow CS. The thorax. In: Farrow CS, ed. *Radiology of the cat*. St Louis: Mosby Year Book Inc, 1994;50–52, 91–93.
12. Harpster NK, Zook BC. Thoracic radiography. In: Holzworth J, ed. *Diseases of the cat. Medicine and surgery*. Philadelphia: WB Saunders Co, 1987;825–831.
13. Suter PF. Radiographic recognition and interpretation of cardiomegaly. In: Suter PF, ed. *Thoracic radiography: a text atlas of thoracic diseases of the dog and cat*. Wettswil, Switzerland: Peter F. Suter, 1984;361–367.
14. Buchanan JW. Radiographic aspects of patent ductus arteriosus in dogs before and after surgery. *Acta Radiol Suppl* 1972;319: 271–278.