Results for FS, which is one of the variables popularly used to assess LVSF in echocardiography, were reported\(^1,2\) to be affected by the body size of dogs. A significant correlation was detected between FS and body size in dogs that differed in body size but that were identical in body conformation.\(^3\) The influence of body size on FS might adversely affect the clinical evaluation of LVSF and make it difficult to render an accurate diagnosis, especially when impaired myocardial function as a result of dilated cardiomyopathy and doxorubicin-induced myocardial toxicosis is suspected.

Two-dimensional STE provides a novel approach for the assessment of LVSF in humans and dogs.\(^4–7\) Improvements in the resolution of 2-D echocardiographic images have enabled the tracking of acoustic markers from frame to frame.\(^7\) This technique has facilitated the noninvasive, angle-independent assessment of strain and left ventricular rotation.\(^8\) In humans, STE analysis has been applied to the assessment of ischemic myocardium in patients with myocardial infarction as well as the identification of regional myocardial deformation, and assessments of

**Objective**—To assess differences in left ventricular contractile indices among dogs of 3 body sizes via 2-D speckle-tracking echocardiography (STE) and to determine body weight–independent systolic variables.

**Animals**—37 clinically normal adult dogs.

**Procedures**—Dogs were allocated into 3 groups on the basis of body weight: small (< 7 kg), medium (7 to 20 kg), and large (> 20 kg). Right parasternal short-axis echocardiographic views were acquired to measure conventional M-mode variables (left ventricular internal diameter at end diastole, left ventricular internal diameter at end systole, and fractional shortening [FS]) and STE indices (peak systolic strain, peak systolic strain rate, synchrony time index [STI], peak systolic apical rotation, peak systolic basal rotation, peak apical twisting rate, and peak systolic torsion). Values were compared among the 3 groups.

**Results**—STE indices, except for peak systolic radial strain (SRad), peak systolic basal rotation, and STI, were significantly decreased in large dogs, compared with values for small and medium dogs. No significant difference was detected in stroke index, peak systolic SRad, and peak systolic basal rotation among the 3 groups. The STI in large dogs was significantly increased, compared with that of medium dogs.

**Conclusions and Clinical Relevance**—Results revealed that decreased systolic indices in large dogs should not be interpreted as signs of decreased systolic function. Increased STI in large dogs may contribute to decreased FS. Because peak systolic SRad was not affected by body weight, peak systolic SRad might be a better variable than FS for assessing systolic function. (Am J Vet Res 2009;71:421–427)
myocardium variability are now being performed, additionally, STE is used for the quantitative assessment of dyssynchrony and the prediction of responses to cardiac resynchronization therapy. It also has been reported that left ventricular systolic strain, strain rate, and rotation-torsion could be used to assess LVSE.

It has been hypothesized that large-breed dogs have contractile profiles and mechanics that differ from those of small-breed dogs and that contraction is more dependent on twisting motion than on contraction in the short-axis direction of the heart represented by FS; furthermore, STE may enable the accurate analysis of myocardial motion, which would make it possible to disclose the difference of left ventricular contractile profiles and mechanics in small, medium, and large dogs. The purpose of the study reported here was to use STE to compare left ventricular contractile indices in small, medium, and large dogs and to determine body weight–independent systolic variables.

Materials and Methods

Dogs—Data were collected from 37 clinically normal adult dogs (7 Chihuahuas, 19 Beagles, 2 Golden Retrievers, 6 Labrador Retrievers, 1 German Shepherd Dog, 1 Newfoundland, and 1 Flat-Coated Retriever) with no history of cardiopulmonary disease or detectable anatomic heart disease and unremarkable physical examination findings, results of ECG, and values for systolic function detected during conventional echocardiography. Dogs were allocated on the basis of body weight to 3 groups: small (<7 kg), medium (7 to 20 kg), and large (>20 kg).

Echocardiographic examination—All echocardiographic images were obtained by an ACVIM-certified cardiologist (YF) by use of an ultrasonography machine on nonanesthetized dogs that were manually restrained in right lateral recumbency. Conventional M-mode echocardiographic measurements (LVId, LVId, and FS) were obtained from the right parasternal short-axis view. Left ventricular SV and EF were calculated from left ventricular internal diameters by use of the Teichholz method. Body surface area was calculated in each dog by use of the following equation:

\[ \text{Body surface area in } m^2 = k \times \left( \text{body weight in g} \right)^{0.667/10^4} \]

where \( k \) is a constant with a value of 10.1. Stroke index was calculated in each dog by use of the following equation:

\[ SI \text{ in } mL/m^2 = SV \times \text{body surface area in } m^2 \]
Electrocardiographic monitoring with clear R–wave recognition was recorded concurrently with an echocardiographic examination by use of the same ultrasonography unit. The period designated as electromechanical systole was measured from the beginning of the QRS complex to the closure of the aortic valve on an M-mode echocardiogram.

STE measurements—Parasternal short-axis views, which were recorded at rates of 39 frames/s to 156 frames/s, were used to measure STE indices. Images with views of the parasternal short axis were acquired in cine loops synchronized with the QRS complex, saved in digital format, and analyzed by use of off-line software (Figure 1). The principles of speckle-tracking analysis were followed as described elsewhere.

Each of 3 cardiac cycles, which were determined from R wave to R wave, were used for STE analysis. Endocardial borders in the end-systolic frame of the 2-D images were manually traced to measure the left ventricular internal diameter at end systole. The computer software automatically tracked myocardial motion and created 6 regions of interest in each image (cranioseptum, cranial, lateral, caudal, ventral, and septum). The tracking quality of myocardial motion was automatically evaluated by the computer software to determine whether it was reliable, and the expression of this was validated or failed. When tracking was described as failed by the computer software, the observer manually examined the trace and made corrections as needed. An assessment of STE indices was regarded as not feasible when a value or values were considered theoretically impossible by the observer.

Peak systolic strain and peak systolic strain rate were measured from parasternal short-axis views near the location of the chordae tendinae of the heart. For both indices, the values in the radial and circumferential direction were calculated in the 6 segments as described. The STI (ie, the difference in timing of the peak systolic SRad from the earliest to the latest segment) was also calculated.

Variables for left ventricular rotation were analyzed by use of right parasternal, left ventricular short-axis views (near the apex of the heart for apical rotation and near the mitral valve for basal rotation). The peak systolic apical rotation, basal rotation, torsion, and peak apical twisting rate were measured. Each value was expressed as the mean of 3 consecutive cardiac cycles, which was the same as the measurement of strain variables. The basal and apical rotation curves were superimposed in a spreadsheet for the calculation of peak systolic torsion.

Statistical analysis—By use of the same cine loops, each STE value was determined again 2 months after the echocardiographic examination by use of the same ultrasonography unit.

### Table 1—Characteristics of dogs among the 3 groups used for the analysis of conventional echocardiographic and peak systolic strain indices and left ventricular rotation and torsion.

<table>
<thead>
<tr>
<th>Indices</th>
<th>Variable</th>
<th>Small dogs</th>
<th>Medium dogs</th>
<th>Large dogs</th>
<th>All dogs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional peak echocardiographic and systolic strain indices</td>
<td>No. of dogs</td>
<td>7</td>
<td>16</td>
<td>11</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>No. of male dogs</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Age (mo)†</td>
<td>41.1 ± 29.2</td>
<td>18.3 ± 10.16</td>
<td>36.1 ± 18.29</td>
<td>28.8 ± 20.19</td>
</tr>
<tr>
<td></td>
<td>Body weight (kg)‡</td>
<td>2.1 ± 0.49</td>
<td>10.7 ± 1.783</td>
<td>25.7 ± 5.054</td>
<td>13.8 ± 8.49</td>
</tr>
<tr>
<td></td>
<td>Body surface area (m²)‡</td>
<td>0.17 ± 0.03</td>
<td>0.49 ± 0.053</td>
<td>0.98 ± 0.111</td>
<td>0.56 ± 0.27</td>
</tr>
<tr>
<td>Left ventricular rotation and torsion</td>
<td>No. of dogs</td>
<td>6</td>
<td>10</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>No. of male dogs</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Age (mo)‡</td>
<td>32.0 ± 17.66</td>
<td>70.1 ± 21.37</td>
<td>33.00 ± 14.95%</td>
<td>50.4 ± 26.45</td>
</tr>
<tr>
<td></td>
<td>Body weight (kg)‡</td>
<td>1.9 ± 0.13</td>
<td>11.8 ± 1.543</td>
<td>27.1 ± 5.845</td>
<td>12.6 ± 9.77</td>
</tr>
<tr>
<td></td>
<td>Body surface area (m²)‡</td>
<td>0.19 ± 0.01</td>
<td>0.52 ± 0.095</td>
<td>0.91 ± 0.133</td>
<td>0.51 ± 0.29</td>
</tr>
</tbody>
</table>

*Groups were as follows: small, < 7 kg; medium, 7 kg to 20 kg; and large, > 20 kg. †Within a row, value differs significantly (P < 0.05) from the value for small dogs. ‡Within a row, value differs significantly (P < 0.01) from the value for medium dogs.

### Table 2—Mean ± SD values for conventional echocardiographic variables and peak systolic strain indices in small, medium, and large dogs.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Small dogs</th>
<th>Medium dogs</th>
<th>Large dogs</th>
</tr>
</thead>
<tbody>
<tr>
<td>R–R interval (ms)</td>
<td>662.18 ± 74.63 (7)</td>
<td>570.21 ± 95.78 (16)</td>
<td>807.11 ± 228.20 (11)</td>
</tr>
<tr>
<td>LVd (mm)</td>
<td>11.30 ± 1.32 (7)</td>
<td>19.43 ± 1.794 (16)</td>
<td>29.18 ± 3.974 (11)</td>
</tr>
<tr>
<td>LVDs (mm)</td>
<td>17.83 ± 1.06 (7)</td>
<td>30.35 ± 2.171 (16)</td>
<td>39.65 ± 4.511 (11)</td>
</tr>
<tr>
<td>FS (%)</td>
<td>37.22 ± 4.42 (7)</td>
<td>29.88 ± 4.80 (16)</td>
<td>26.48 ± 2.47 (11)</td>
</tr>
<tr>
<td>EF (%)</td>
<td>69.62 ± 5.44 (7)</td>
<td>66.58 ± 6.16 (16)</td>
<td>52.27 ± 4.08 (11)</td>
</tr>
<tr>
<td>SV (mL)</td>
<td>6.64 ± 0.96 (7)</td>
<td>24.30 ± 5.084 (16)</td>
<td>36.21 ± 8.434 (11)</td>
</tr>
<tr>
<td>SI (mL/m²)</td>
<td>40.70 ± 6.77 (7)</td>
<td>49.83 ± 10.20 (16)</td>
<td>41.53 ± 9.55 (11)</td>
</tr>
<tr>
<td>Total electromechanical systole (ms)</td>
<td>166.28 ± 15.22 (6)</td>
<td>182.60 ± 15.69 (10)</td>
<td>218.40 ± 33.213 (5)</td>
</tr>
<tr>
<td>Peak systolic SCir (%)</td>
<td>-24.25 ± 2.85 (7)</td>
<td>-20.94 ± 1.967 (16)</td>
<td>-16.71 ± 2.564 (11)</td>
</tr>
<tr>
<td>Peak systolic SRad (%)</td>
<td>55.24 ± 11.62 (7)</td>
<td>48.21 ± 8.87 (16)</td>
<td>50.33 ± 7.05 (11)</td>
</tr>
<tr>
<td>Peak systolic SCr (l/s)</td>
<td>-2.92 ± 0.27 (7)</td>
<td>-3.05 ± 0.34 (16)</td>
<td>-2.05 ± 0.47 (11)</td>
</tr>
<tr>
<td>Peak systolic SRad/l/s</td>
<td>3.00 ± 0.31 (7)</td>
<td>3.41 ± 0.64 (16)</td>
<td>2.51 ± 0.56 (11)</td>
</tr>
<tr>
<td>STI (ms)</td>
<td>31.57 ± 15.48 (7)</td>
<td>27.00 ± 14.82 (9)</td>
<td>46.90 ± 14.48 (10)</td>
</tr>
</tbody>
</table>

Values in parentheses are the number of dogs evaluated in each category.

*Groups were as follows: small, < 7 kg; medium, 7 kg to 20 kg; and large > 20 kg. †Within a row, value differs significantly (P < 0.05) from the value for small dogs. ‡Within a row, value differs significantly (P < 0.01) from the value for small dogs. §Within a row, value differs significantly (P < 0.05) from the value for medium dogs.
the primary analysis and used for statistical evaluation. Although STE analysis was performed by a single observer (HT), intraobserver variability was assessed via a coefficient of variation for each STE measurement by use of images from 5 medium dogs. Systolic functional indices of conventional echocardiography, strain analysis, and left ventricular rotation analysis among small, medium, and large dogs were compared. Normally distributed data were analyzed by use of a 1-way ANOVA. Nonnormally distributed data were analyzed by use of the Kruskal-Wallis test. When a significant difference was detected, multiple comparisons were evaluated by use of a Scheffé F test. A multivariate analysis with application of a multiple regression analysis was performed to determine the effects of sex, age, and R–R interval on STE indices. Data were expressed as mean ± SD. A value of $P < 0.05$ was considered significant.

**Results**

Speckle-tracking echocardiography resulted in technically adequate images in 96.67%, 93.68%, and 88.33% of small, medium, and large dogs, respectively. The coefficient of variation of all intraobserver values for STE ranged from 0% to 6.3%. The characteristics of each group and the number of dogs used were summarized (Table 1). Results of the systolic functional indices for conventional echocardiography, strain analysis, and left ventricular rotation analysis were recorded for small, medium, and large dogs (Figures 2 and 3; Tables 2 and 3). Fractional shortening and EF in large dogs were significantly ($P < 0.01$) decreased, compared with those in small and medium dogs. The R–R intervals of images near the location of the chordae tendinea of the heart in large dogs were significantly ($P < 0.01$) increased, compared with those in medium dogs, and those of both apical and basal images in large dogs were significantly ($P < 0.05$) increased, compared with those in small and medium dogs. Furthermore, the total electromechanical systole was significantly increased in large dogs, compared with that in small ($P < 0.01$) and medium ($P < 0.05$) dogs.

The STI in large dogs was significantly increased, compared with that in medium dogs. Peak systolic SCir, peak systolic SrCir, and peak apical twisting rate in large dogs were significantly ($P < 0.01$) decreased, compared with those in small and medium dogs. In addition, peak systolic apical rotation in large dogs was significantly decreased, compared with that in small ($P < 0.01$) and medium ($P < 0.05$) dogs. The STI in large dogs was significantly increased, compared with that in medium dogs. Peak systolic SCir, peak systolic SrCir, and peak apical twisting rate in large dogs were significantly ($P < 0.01$) decreased, compared with those in small and medium dogs. In addition, peak systolic apical rotation in large dogs was significantly decreased, compared with that in small ($P < 0.01$) and medium ($P < 0.05$) dogs. The peak systolic SrCir in large dogs was significantly ($P < 0.01$) reduced, compared with that in medium dogs. Peak systolic torsion in large dogs was significantly ($P < 0.01$) reduced, compared with that in small dogs. The STE indices and FS in large dogs were significantly less, compared with those in small and medium dogs. Despite decreased systolic variables in large dogs, no significant difference...
was detected among the 3 groups of dogs for SI, peak systolic SRad, and peak systolic basal rotation.

As a result of a multivariate analysis, a significant correlation was detected between the R–R interval and peak systolic SCir \((r = 0.42; P = 0.016)\), peak systolic SrCir \((r = 0.61; P < 0.001)\), peak systolic SRad \((r = -0.63; P < 0.001)\), peak systolic apical rotation \((r = -0.50; P = 0.029)\), and peak apical twisting rate \((r = 0.68; P = 0.001)\). Additionally, a significant correlation \((r = 0.40; P = 0.022)\) was detected between peak systolic SRad and age. Age and sex did not influence STE variables.

Strain variables were compared between groups (7 small, 12 medium, and 6 large dogs) matched on the basis of R–R interval to eliminate the influence of R–R interval. Mean ± SD FS in large dogs \((27.7 ± 2.64\%)\) was significantly \((P < 0.01)\) decreased, compared with that in small \((37.2 ± 4.42\%)\) and medium \((33.5 ± 4.23\%)\) dogs. Mean peak systolic SCir in small dogs \((-24.25 ± 2.85\%)\) was significantly increased, compared with that in medium \((-20.76 ± 1.64\%; P < 0.05)\) and large \((-17.91 ± 2.85\%; P < 0.01)\) dogs. Mean peak systolic SrCir in large dogs \((-2.35 ± 0.35\%)\) was significantly decreased, compared with that in small \((-2.92 ± 0.27/s; P < 0.05)\) and medium \((-2.96 ± 0.33/s; P < 0.01)\) dogs.

**Discussion**

In the study reported here, STE indices and conventional echocardiographic variables were compared among small, medium, and large dogs with significantly different body weights. We initially hypothesized that myocardial contraction in large dogs was more dependent on twisting motion than on contraction in the short-axis direction. Except for peak systolic SRad in large dogs, indices with strain analysis were significantly lower than in groups of dogs with lower body weights, which was the same pattern observed for FS. Peak systolic torsion was also significantly lower in medium and large dogs, compared with that in small dogs, because peak systolic apical rotation in medium and large dogs was decreased without a significant difference in peak systolic basal rotation among the 3 groups of dogs. None of the variables indicating systolic function in large dogs were higher than those in small and medium dogs. Therefore, our original hypothesis was disproved by these results.

However, other reports\(^{19,23}\) have revealed no significant correlation between body weight and peak systolic SRad, peak systolic SRad, peak systolic apical rotation, or peak systolic torsion. This inconsistency could be a result of differing distributions of body weight among the dogs used in those studies\(^{19,22}\) which included a mean body weight of 22.7 ± 11.2 kg and was much heavier than the mean \((13.8 ± 9.49 \text{ kg})\) in the study reported here. Furthermore, dogs used in our study were more equally distributed among small, medium, and large dogs. Therefore, our population of dogs was adequate for determining whether body weight affected the myocardial contraction mechanics.

The decrease in strain variables reported in the present study could have been a result of the influence of the R–R interval. Negative correlations between the R–R interval and peak systolic SRad and peak systolic SRad in dogs were similar to the results of another study\(^{23}\). A longer R–R interval could be caused by an increase in vagal tone, which results in a decrease in contractility. A study\(^{23}\) was conducted to determine changes in myocardial SRad and peak systolic SRad during pacing-induced alterations in heart rate. The results illustrated that a decrease in myocardial strain was related to an increase in heart rate, which was not in agreement with our results. If a decrease in diastolic period, which resulted in a decrease in SV, had influenced the echocardiographic systolic indices for strain analysis, the correlations between the R–R interval and strain variables should have been positive. Further analysis of our results revealed that a significant decrease in some STE variables (peak systolic SCir and SrCir) in large dogs still existed in the groups matched on the basis of

![Figure 3](image-url)
R–R interval. Therefore, the decreased strain variables reported in large dogs were more affected by the size of the dog than by changes in the R–R interval.

In general, the echocardiographic systolic indices are influenced by autonomic tone, preload, and afterload. The decreased systolic indices in large dogs of the study reported here could possibly have been caused by an increase in afterload, decrease in preload, or both, compared with systolic indices in small and medium dogs. As explained by Laplace’s law, anatomically large hearts may have increased left ventricular wall stress. It is reported that the calculated wall stress at end diastole (which reflects the preload) and end systole (which reflects the afterload) are similar among species with remarkably different body weights. Therefore, the influence of preload and afterload should also be minimal within species.

The STI was significantly prolonged in large dogs. Thus, each left ventricular segment contracted in the short-axis direction in a less synchronized manner and could have been one of the causes of the relatively low FS in large dogs. Although the specific mechanism remains unclear, the time required for propagation of left ventricular systole may be prolonged because of the large size of the heart in larger dogs. Although STI was significantly greater and FS was significantly less in large dogs, there was no significant difference in SI and peak systolic SRad among the 3 groups of dogs, which suggested that cardiac output and systolic function should be maintained. Because it was unaffected by body weight, peak systolic SRad might be a better systolic variable than FS or the other systolic STE indices (peak systolic SCir, SrCir, SRad, apical rotation, torsion, and peak apical twisting rate). Because FS was calculated from the systolic motion of the short-axis for 2 specific left ventricular segments, FS may not reflect the systolic function of the entire heart.

It was reported that indices of systolic function such as FS, EF, and end-systolic volume index were significantly decreased in large dogs, compared with values in small dogs; similarly, this was the same pattern observed in our results. The EF, which was estimated by use of the area-length method and reflected both short- and long-axis contributions to systolic function, did not differ between small and large dogs. Analysis of our results revealed that left ventricular torsion in large dogs was decreased, compared with that in smaller dogs; this suggested that torsion may not be the predominant motion of systolic function in large dogs. Results of allometric analysis among multiple mammals illustrated the relationship between mitral annulus velocity, displacement, and long-to-short axis displacement ratio scale to the size of the heart. In that study, investigators found that these relationships revealed a reduction in the relative long-axis contribution to cardiac function in small mammals. Although such an analysis was not included in the present study, an analysis of systolic function in the long-axis view would be needed to properly investigate the difference in systolic motion patterns between small and large dogs.

Another possible reason that systolic indices were decreased could have been the geometric structure of the heart in large dogs. Because the heart was estimated to have an ellipsoid-like shape, SV relative to body weight could increase if FS is the same when the end-diastolic diameter becomes larger, which is the case in large dogs. If the cell metabolism were the same within species, anatomically larger hearts might become efficient enough to eject an SV that would suffice to meet the oxygen-delivery demands of peripheral tissues. Therefore, the heart in large dogs may not need to contract in a manner similar to that of smaller dogs because of this inherent geometric advantage.

The study reported here had several limitations. First, we did not perform an evaluation of STE analysis in the left ventricular long-axis direction. Although an STE analysis in the left ventricular long-axis direction was attempted by use of a left parasternal apical 2- or 4-chamber view, the technique proved technically difficult, especially in large dogs, for obtaining high frame rates in that view or providing an endocardium view that was sufficiently clear to allow off-line analysis. Second, the population of dogs used for analysis of left ventricular rotation differed significantly among the groups with regard to sex and age. Third, the small and medium dogs comprised only 1 particular breed. Therefore, our results may not represent the overall dog population. Further evaluations with a variety of breeds would be warranted to determine whether there are breed-specific characteristics.

The use of STE provided an objective measure for quantifying regional ventricular function. This modality has been effectively evaluated for the diagnosis of various heart diseases and for determination of therapeutic efficacy, especially in human medicine for patients with ischemic heart disease and patients receiving cardiac resynchronization therapy. Although ischemic heart disease and use of cardiac resynchronization therapy are not commonly part of veterinary medicine, STE might be beneficial in the detection of early cardiac disease or injury or for determining the cause of heart disease.

Analysis of results of an in vitro study has suggested that different strain magnitudes affect the synthesis of specific glycosaminoglycans and proteoglycans by valvular interstitial cells. In the field of veterinary cardiology, atrioventricular valvular disease is more commonly diagnosed in dogs of small breeds than in dogs of large breeds. Overall, our results suggested that STE indices in large dogs were lower than those in small and medium dogs. Although further investigation is needed, differing biomechanical functions of the heart might be one of the reasons for the higher prevalence of mitral valve disease in small-breed dogs.

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