Quantification, repeatability, and reproducibility of feline radial and longitudinal left ventricular velocities by tissue Doppler imaging

Valérie Chetboul, DVM, PhD; Nicolas Athanassiadis, DVM; Carolina Carlos, DVM; Audrey P. Nicolle, DVM; Renaud Tissier, DVM; Jean-Louis Pouchelon, DVM, PhD; Didier Concordet, DVM, PhD; Hervé P. Lefebvre, DVM, PhD

Objective—To measure the radial and longitudinal velocities of several myocardial segments of the left ventricular wall by use of tissue Doppler imaging (TDI) in healthy cats and determine the repeatability and reproducibility of the technique.

Animals—6 healthy cats.

Procedure—72 TDI examinations were performed on 4 days by the same trained observer. Radial parameters included left endocardial and epicardial myocardial velocities. Longitudinal parameters included left basal, middle, and apical myocardial velocities.

Results—All velocity profiles had 1 positive systolic wave (S) and 2 negative diastolic waves (E and A). Myocardial velocities were higher in the endocardial than epicardial segments during the entire cardiac cycle (systolic wave S, 4.4 ± 0.82 and 1.9 ± 0.55; diastolic wave E, 9.7 ± 1.70 and 2.2 ± 0.74; and diastolic wave A, 5.1 ± 1.56 and 1.4 ± 0.76, respectively). Velocities were also higher in the basal than in the apical segments (systolic wave S, 4.7 ± 0.76 and 0.2 ± 0.11; diastolic wave E, 9.7 ± 1.36 and 0.5 ± 0.17; and diastolic wave A, 3.7 ± 1.51 and 0.2 ± 0.13, respectively). The lowest within-day and between-day coefficients of variation were observed in endocardial segments (8.2% and 6.5% for systolic wave S and diastolic wave E, respectively) and in the basal segment in protodiastole (5.5%).

Conclusions and Clinical Relevance—Repeatability and reproducibility of TDI were adequate for measurement of longitudinal and radial left ventricular motion in healthy awake cats. Validation of TDI is a prerequisite before this new technique can be recommended for clinical use. (*Am J Vet Res* 2004; 65:566–572)

Cardiomyopathies include various disorders with structural abnormalities and functional impairments of the myocardium.[1] Results of echocardiography[2] and necropsy[2,3] studies indicate that cardiomyopathies are the most serious category of heart diseases in cats. Early diagnosis of cardiomyopathies is a major concern because these diseases are the most frequent cause of sudden death, heart failure, and systemic thromboembolism in cats,[4,5] especially in breeds such as Maine Coon,[6] Persian,[a] and domestic shorthair cat,[b] which are predisposed to heritable cardiomyopathies.

Diagnosis of these cardiomyopathies is presently determined by qualitative and quantitative information on the heart (myocardial and cardiac chamber dimensions, systolic and diastolic myocardial function, and the presence or absence of left ventricular outflow obstruction) obtained by echocardiographic and Doppler examinations. Unfortunately, these 2 conventional ultrasonographic techniques are not considered to be sufficiently sensitive to detect early functional myocardial changes. Results of 1 study[7] in humans indicate that **tissue Doppler imaging (TDI)** may be a valuable tool for diagnosing cardiomyopathies. This new ultrasonographic technique permits quantification of regional myocardial function by measurement of myocardial velocities[8] for radial[9,10] and longitudinal movements.[11,12] Therefore, any change in the complete myocardial movement during the cardiac cycle can be detected early.

In veterinary cardiology, little information on TDI is presently available. In dogs, early diagnosis of cardiomyopathies may be possible with TDI. Results of previous studies[c,d] indicate that TDI is more sensitive and specific than conventional echocardiography for detecting myocardial dysfunction in a model of dilated cardiomyopathy. Results of another study[13] indicate detection of radial and longitudinal myocardial motion by use of TDI in cats; however, only 1 myocardial segment per wall was documented, pulse-wave TDI was used rather than color TDI, and data on repeatability and reproducibility were not provided. This latter point is a prerequisite for performing any longitudinal study to evaluate the sensitivity of TDI for detecting early myocardial dysfunction.

The purpose of the study reported here was to measure the radial and longitudinal velocities of several myocardial segments of the left ventricular wall by use of TDI in healthy cats and determine the repeatability and reproducibility of the technique.

Materials and Methods

Animals—Animal procedures were approved by the Animal Use and Care Committee of the National Veterinary

Received August 18, 2003.
Accepted October 20, 2003.
From Unité de Cardiologie d'Alfort, Ecole Nationale Vétérinaire d'Alfort, 7 Avenue du Général de Gaulle, 94 704 Maisons-Alfort cedex, France (Chetboul, Carlos, Nicolle, Pouchelon); Equipe mixte INSERM-Université 00-01, Kremlin-Bicêtre, France (Chetboul, Tissier, Pouchelon); and Unité Mixte de Recherches 181 Physiopathologie et Toxicologie Expérimentales, Ecole Nationale Vétérinaire de Toulouse, 23 chemin des Capelles, 31076 Toulouse Cedex 03, France (Athanassiadis, Concordet, Lefebvre).
Address correspondence to Dr. Chetboul.

School of Alfort and conducted in accordance with guidelines established by the National Institutes of Health Guide for the Care and Use of Laboratory Animals. Six young healthy sexually intact female Chartreux cats were used in the study. Mean ± SD age and weight of the cats were 3.1 ± 1.7 years and 4.5 ± 0.7 kg, respectively. All cats were determined to be healthy on the basis of a complete clinical examination, blood pressure measurement, ECG, and standard echocardiography performed just before the study.

Color TDI—Two-dimensional color TDI examinations were performed with continuous ECG monitoring by use of an ultrasound machine[e] equipped with a 5.5 to 7.5-MHz, phased-array transducer. For each TDI examination, heart rate was determined by ECG. Grayscale receive gain was set to optimize the clarity of the left endocardial and epicardial boundaries. Segmental myocardial motion was measured offline from color Doppler images of the left myocardial wall. Real time color Doppler was superimposed on grayscale with a frame rate ≥ 100 frames/s. Doppler receive gain was adjusted to maintain optimal coloring of the myocardium, and Doppler velocity range was set as low as possible to avoid occurrence of aliasing. Digital images were obtained and stored, then reviewed later on a stand-alone offline measuring system.[f] Nine × 9 pixel sampling (2 × 2 mm) was used, and a tissue velocity profile was displayed in each sample location.

Measurement of myocardial velocities resulting from the left ventricular radial motion was performed by use of the right parasternal ventricular short-axis view between the 2 papillary muscles (**Fig 1**). The angle of interrogation of the beam was carefully aligned to be perpendicular to the left ventricular posterior wall. Measurements were made in 2 myocardial segments (endocardial and epicardial) of the left ventricular posterior wall. Endocardial and epicardial velocity profiles were measured simultaneously during the offline analysis.

Measurement of myocardial velocities resulting from the left ventricular longitudinal motion was obtained by use of the standard left apical 4-chamber view (**Fig 2**). The angle of interrogation of the beam was carefully aligned to be parallel to the left ventricular caudal wall. Measurements were made in 3 myocardial segments (basal or annular segment, middle segment [at the level of the maximal diastolic opening of the posterior mitral valve leaflet], and apex) of the left ventricular caudal wall. Basal, middle, and apical velocity profiles were measured simultaneously during the offline analysis.

Assessment of between- and within-day TDI variability—All TDI examinations were randomized, and the observer performed the velocity measurements for each examination with callipers, but could not visualize the values on the screen. Another observer collected all data.

To determine the within-day and between-day variability of the TDI technique, a total number of 72 TDI examinations (36 radial and 36 longitudinal) were performed by the same trained observer on 4 different days during a 2-week period in the 6 cats. For a given cat, the radial examination was performed first from the right side of the thorax, and then the longitudinal examination was performed from the left side of the thorax. For a given day, 3 cats were examined at 3 different and nonconsecutive times. For each velocity, 2 measurements were obtained on 2 consecutive cardiac cycles in the same frame, and the mean of those 2 measurements was calculated. This mean value was used for the statistical analyses (ie, for the determination of the within-day and between-day variability and also for the comparison of the different segmental myocardial velocities).

Statistical analyses—Data are expressed as mean ± SD. Statistical analyses were performed by use of computer software.[g] For the radial motion, a Student paired *t* test was used to compare the endocardial and epicardial velocities. For the longitudinal motion, basal, middle, and apical velocities were compared by use of ANOVA with repeated measures followed, if necessary, by a post-hoc Student *t* test with the Bonferroni correction. The same tests were used to compare systolic, protodiastolic, and telediastolic velocities in each segment. Heart rates, which were measured during each TDI examination, were compared at the different times of the protocol by use of ANOVA with repeated measures. Correlations between the heart rate and the different myocardial velocities (endocardial, epicardial, basal, middle, and apical) were examined by use of Pearson product moment correlation.

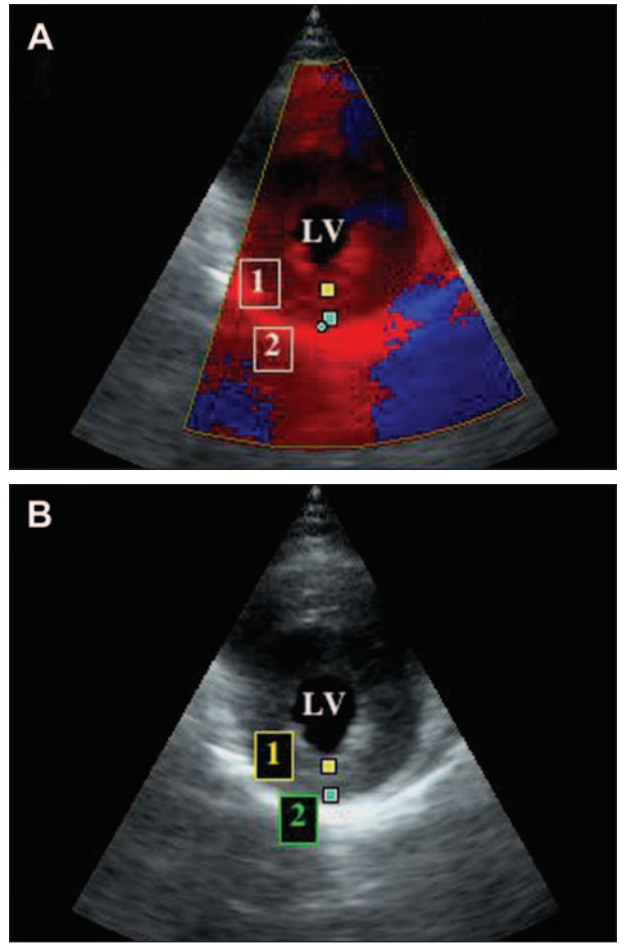
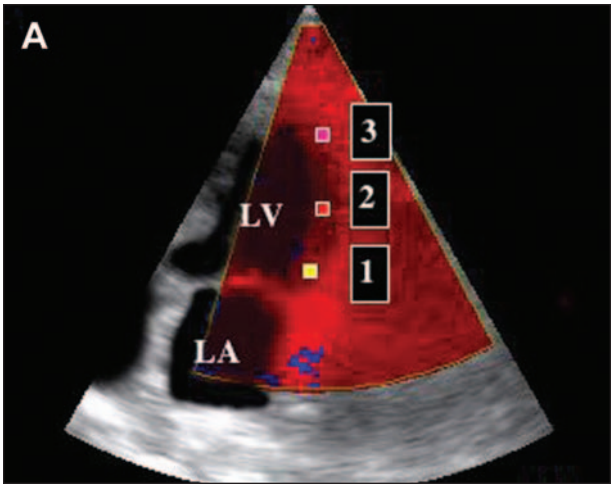


Figure 1—Two-dimensional color tissue Doppler imaging (TDI) mode (A) recorded from the right parasternal short-axis view (B) of the heart in a cat. Notice the location of the 2 myocardial segments for the left ventricular radial motion analysis. 1 = Endocardial segment. 2 = Epicardial segment. LV = Left ventricle.

To determine the within-day and between-day variability, the following general linear model was used for each TDI parameter:

$$Y_{ijk} = \mu + day_i + cat_j + (day \times cat)_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} is the kth value measured for cat j on day i, μ is the mean of the observed values, day_i is the differential effect of day i, cat_j is the differential effect of cat j, $(day \times cat)_{ij}$ is the interaction term between day and cat, and ε_{ijk} is the model error. The SD of repeatability was estimated as the residual SD of the model, and the SD of reproducibility was estimated as the SD of the differential effect of day. Values of $P < 0.05$ were considered significant.



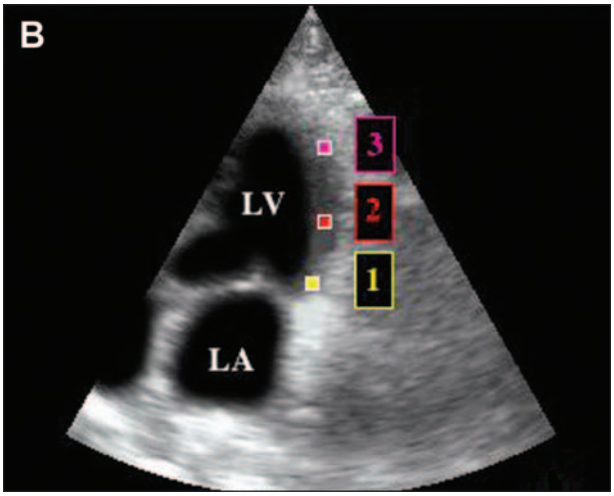


Figure 2—Two-dimensional color TDI mode (A) recorded from the left apical 4-chamber view (B) of the heart of a cat. Notice the location of the 3 myocardial segments for left ventricular longitudinal motion analysis. 1 = Basal segment. 2= Middle segment. 3 = Apical segment. LA = Left atrium. *See* Fig 1 for key.

Results

General description of the left ventricular motion—All velocity profiles included 1 positive systolic wave (S) and 2 negative diastolic waves (E and A, respectively, in proto- and telediastole; **Fig 3 and 4**) or only 1 negative diastolic wave (EA) when diastolic waves E and A were summated owing to rapid heart rate **(Fig 5)**. They also included 2 isovolumic phases: the isovolumic contraction phase (from the end of the negative diastolic wave A to the beginning of the positive systolic wave S) and the isovolumic relaxation phase (from the end of the systolic wave S to the first negative diastolic wave E). Good regional synchrony was also observed between the endocardial and epicardial layers for the radial motion (Fig 3) and between the basal, middle, and apical segments for the longitudinal motion (Fig 4 and 5).

Left ventricular radial motion—Heart rate did not differ significantly between the sequential radial TDI examinations. Fusion of the 2 negative diastolic waves E and A into 1 negative diastolic wave (EA) was observed in 17 of 36 TDI radial examinations. The observed maximal heart rate permitting identification

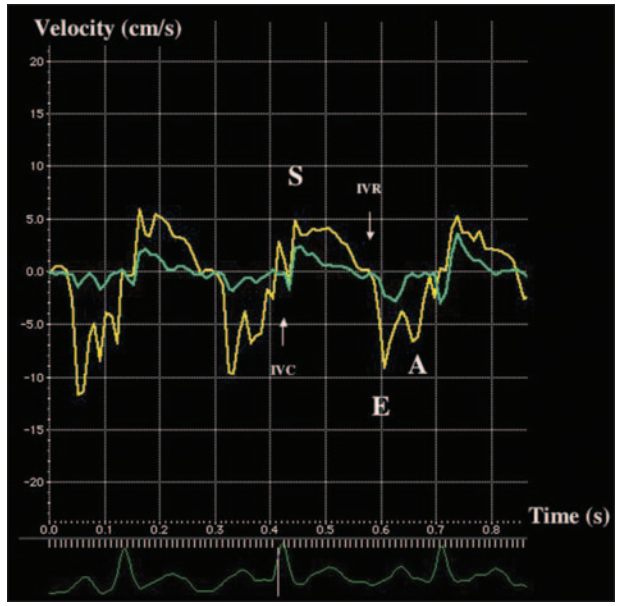


Figure 3—Left ventricular segmental radial motion obtained via TDI and recorded from the right parasternal short-axis view of the heart of a cat. The simultaneous recording of the velocities in the endocardial (yellow) and epicardial (green) segments indicates that the endocardial segments are moving more rapidly than the epicardial segments in systole and also in diastole. A = Peak velocity of the left ventricular posterior wall during late diastole. E = Peak velocity of the left ventricular posterior wall during early diastole. IVC = Isovolumic contraction phase. IVR = Isovolumic relaxation phase. S = Peak velocity of the left ventricular posterior wall during systole.

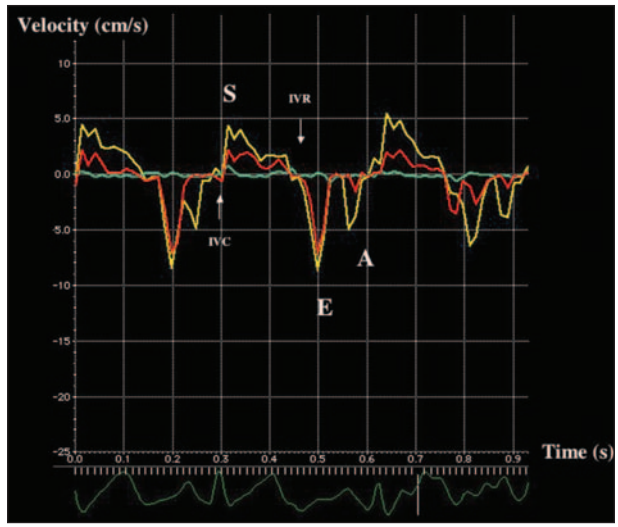


Figure 4—Left ventricular segmental longitudinal motion obtained via TDI and recorded from the left apical 4-chamber view of the heart of a cat. The simultaneous recording of the velocities in the basal (yellow), middle (red), and apical (green) segments indicates that the basal segments are moving more rapidly than the middle and apical segments during the entire cardiac cycle. *See* Figure 3 for key.

of diastolic waves E and A was 220 beats/min. During the entire cardiac cycle, myocardial velocities (cm/s) were significantly ($P < 0.001$) higher in the endocardial than in the epicardial segments (Fig 3 and **Table 1**). Diastolic myocardial velocities (cm/s) were significantly ($P < 0.001$) higher in protodiastole than in telediastole in both segments. Diastolic wave E was also

significantly higher than systolic wave S in the endocardial ($P < 0.001$) and epicardial segments ($P < 0.05$). Diastolic wave A was significantly ($P < 0.01$) higher than systolic wave S in the endocardial, but not the epicardial, segment.

Because diastolic waves E and A were summated in 47% of TDI radial examinations, the correlation and variability studies in diastole were only performed for diastolic wave E. Summated diastolic waves E and A (wave EA) were considered as diastolic wave E because the respective means ± SD were similar, (ie, 10.2 ± 1.36 and 9.2 ± 1.78 for diastolic waves E and EA in the endocardial segment, respectively, and 2.2 ± 0.53 and 2.2 ± 0.86 for diastolic waves E and EA in the epicardial segment, respectively).

A significant ($P < 0.001$) correlation ($r = 0.73$ and 0.59, for the endocardial and epicardial segment velocities, respectively) was observed between heart rate and the systolic velocities (**Fig 6**). A significant ($P < 0.001$) correlation ($r = 0.76$) was also observed between heart rate and the protodiastolic velocities in the endocardial segment, but not in the epicardial segment ($r = 0.29$; $P > 0.05$).

The within-day **coefficients of variation** (CV) were 8.2% and 20.0% for systolic wave S and 6.5% and 28.9% for diastolic wave E in the endocardial and epicardial segments, respectively. The between-day CV values were 50.0% for systolic wave S in the epicardial segment and 13.6% and 39.9% for diastolic wave E in

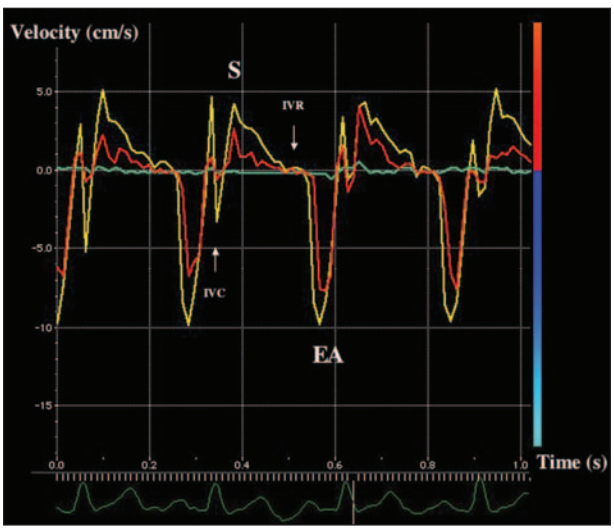


Figure 5—Left ventricular segmental longitudinal motion obtained via TDI and recorded from left apical 4-chamber view of the heart in a cat. An example of fusion between the 2 negative diastolic waves E and A. EA = Peak velocity of the left ventricular caudal wall during diastole. *See* Figure 3 for remainder of key.

Table 1—Mean ± SD radial left ventricular velocities (cm/s) measured in the endocardial and epicardial segments obtained via tissue Doppler imaging (TDI) in 6 awake healthy cats

Wave	Endocardial	Epicardial
Systolic wave S	4.4 ± 0.82[a]	1.9 ± 0.55
Diastolic wave E	9.7 ± 1.70[a]	2.2 ± 0.74
Diastolic wave A	5.1 ± 1.56[a]	1.4 ± 0.76

[a]Significantly ($P < 0.001$) different from value in the epicardial segment.
A = Peak velocity of the left ventricular posterior wall during late diastole. E = Peak velocity of the left ventricular posterior wall during early diastole. S = Peak velocity of the left ventricular posterior wall during systole.

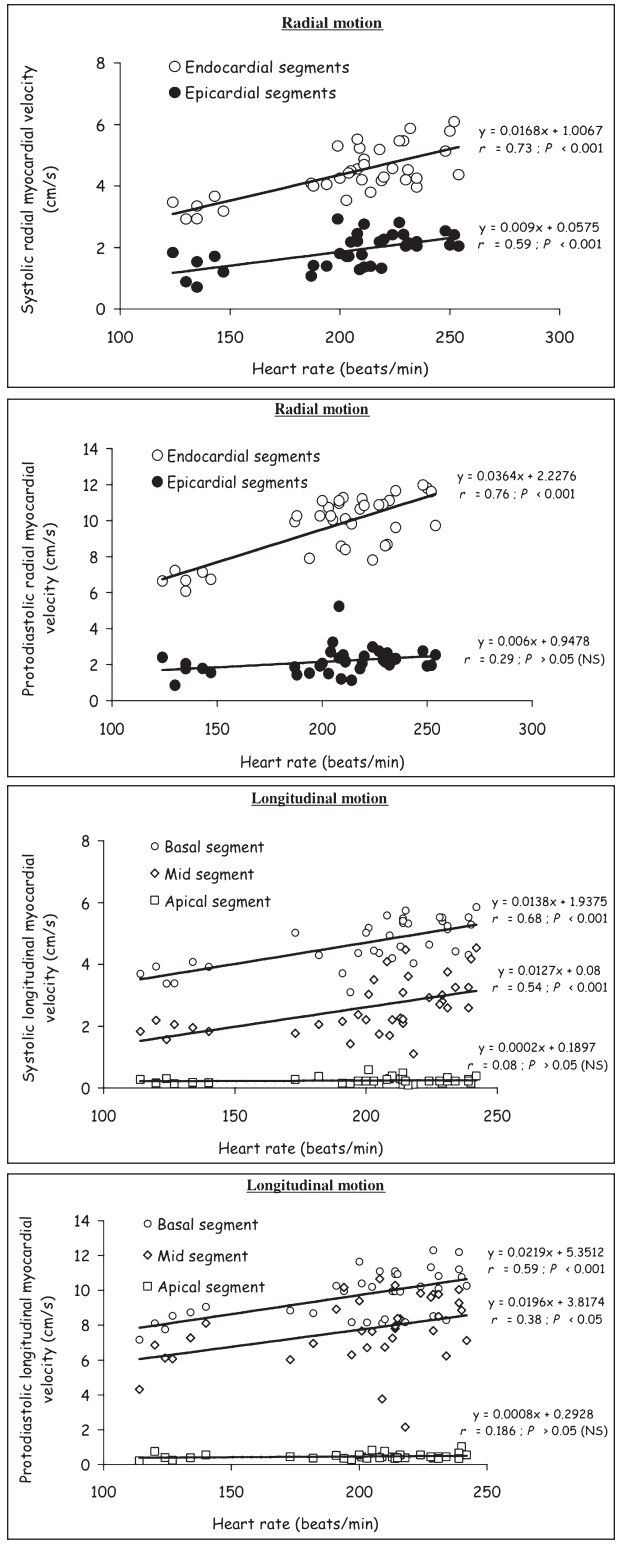


Figure 6—Correlations between heart rate and myocardial velocities in systole and in protodiastole for the radial and longitudinal motion of the endocardial, epicardial, basal, middle, and apical segments measured via TDI (n = 36 for each segment) in 6 awake healthy cats. NS = Not significant.

the endocardial and epicardial segments, respectively. A significant interaction between cat and day was observed for systolic wave S in the endocardium ($P < 0.01$), which indicates that values observed in the different cats were not ranked in the same order from 1 day to another. Therefore, SD and CV values of reproducibility could not be estimated for this parameter.

Left ventricular longitudinal motion—Heart rate did not differ significantly between the sequential longitudinal TDI examinations. Fusion of the 2 negative diastolic waves E and A into 1 negative diastolic wave EA was observed in 23 of 36 TDI longitudinal examinations (Fig 5). The observed maximal heart rate permitting identification of diastolic waves E and A was 224 beats/min. During the entire cardiac cycle, myocardial velocities were significantly ($P < 0.001$) higher in the basal than in the apical segment, in the basal than in the middle segment, and in the middle than in the apical segment (Fig 4 and **Table 2**). Diastolic myocardial velocities were significantly ($P < 0.001$) higher in protodiastole than in telediastole in the 3 segments. Diastolic wave E was also significantly ($P < 0.001$) higher than systolic wave S in all 3 segments. Systolic wave S was never significantly different from diastolic wave A.

Because diastolic waves E and A were summated in 64% of TDI longitudinal examinations, the correlation and variability studies in diastole were only performed for diastolic wave E. Summated diastolic waves E and A (wave EA) were considered as diastolic wave E because the respective means ± SD were similar (ie, 10.1 ± 1.46 and 9.2 ± 1.08 for diastolic waves E and EA in the basal segment; 7.9 ± 1.56 and 7.5 ± 1.58 for diastolic waves E and EA in the middle segment; and 0.5 ± 0.11 and 0.5 ± 0.18 for diastolic waves E and EA in the apical segment, respectively).

A significant correlation was observed between heart rate and the basal segment velocities in systole ($r = 0.68$; $P < 0.001$) and protodiastole ($r = 0.59$; $P < 0.001$; Fig 6). A significant correlation was also observed between heart rate and the middle segment velocities in systole ($r = 0.54$; $P < 0.001$) and protodiastole ($r = 0.38$; $P < 0.05$). No correlation was found between heart rate and the apical segment velocities ($r = 0.08$ and $r = 0.186$, in systole and protodiastole, respectively; $P > 0.05$).

The within-day CV values were 8.3%, 23.4%, and 48.6% for systolic wave S and 8.8%, 18.8%, and 36.0% for diastolic wave E in the basal, middle, and apical myocardial segments, respectively. The between-day CV values were 26.2%, 30.1%, and 24.7% for systolic wave S and 5.5%, 17.6%, and 73.7% for diastolic wave E in the basal, middle, and apical myocardial segments, respectively.

Table 2—Mean ± SD longitudinal left ventricular velocities (cm/s) measured in the basal, mid, and apical segments obtained via TDI in 6 awake healthy cats

Wave	Basal	Middle	Apical
Systolic wave S	4.7 ± 0.76[a,b]	2.6 ± 0.88[c]	0.2 ± 0.11
Diastolic wave E	9.7 ± 1.36[a,b]	7.7 ± 1.91[c]	0.5 ± 0.17
Diastolic wave A	3.7 ± 1.51[a,b]	2.1 ± 1.45[c]	0.2 ± 0.13

[a]Significantly ($P < 0.001$) different from value in the apical segment.
[b]Significantly ($P < 0.001$) different from value in the middle segment.
[c]Significantly ($P < 0.001$) different from value in the apical segment.
See Table 1 for key.

Discussion

In the study reported here, the velocities of different myocardial segments were analyzed in healthy cats by use of TDI, and the within- and between-day variability of this new imaging technique was assessed by recording a large number of motions of myocardial segments (n = 180; 5 different segments examined 36 times each). Three TDI modes (pulse-wave, 2-dimensional color, and M-mode color) can be used to analyze myocardial velocities. Higher temporal resolution and a greater signal-to-noise ratio is obtained by use of M-mode color TDI, compared with the other 2 modes.[14] However, compared with the pulse-wave TDI mode previously used in cats,[13] 2-dimensional color TDI mode, as used in the study presented here, provides better visualization of myocardial movements because all velocity data are displayed simultaneously on the screen.[14]

Results of our study indicated that in cats, the heart has 2 different types of intrinsic myocardial motion, radial and longitudinal, similar to that in humans. These 2 motions were recorded with 2 different views; the right parasternal ventricular short-axis view and the left apical 4-chamber view were used for radial and longitudinal motion, respectively. The 2 left ventricular motions are caused by different myocardial fibers, which are located in the middle portion of the myocardial wall for the radial motion and in the subendocardium for the longitudinal motion.[11] Therefore, TDI permits a complete analysis of the left myocardium that is clinically relevant because these particular myocardial layers may be altered separately and to various degrees in certain lesions.[11]

In our study, all radial and longitudinal velocity profiles had 1 positive systolic wave (S) after a short isovolumic contraction phase and 1 (EA) or 2 (E and A) negative diastolic waves after a short isovolumic relaxation phase. Consequently, the left myocardial wall moved in opposite directions in systole and diastole. Results of previous studies[h,i] in normal dogs indicate that the left ventricular posterior wall moves once toward the transducer (or thoracic wall) during systole and once or twice away from the transducer (or thoracic wall) during diastole.

In our study, the typical diastolic myocardial motion included an early rapid motion (diastolic wave E) and a late slower motion concomitant with the atrial contraction (diastolic wave A), with wave E being significantly greater than wave A in all myocardial segments. However, as with transmitral blood flow velocity patterns obtained with conventional pulse-wave Doppler, increased heart rate caused fusion of myocardial E and A wave velocities in a high percentage of examinations (47% to 64%). This summation has not been observed in healthy dogs[h,i] and represents a disadvantage of the TDI technique in cats because, as with

transmitral velocity patterns obtained in this species by use of conventional pulse-wave Doppler, summation of diastolic waves E and A makes interpretation of diastolic myocardial movements in cats more difficult than in dogs or humans.

In the study reported here, all time velocity plots had good regional synchrony during the entire cardiac cycle for the radial and longitudinal motion. We may hypothesize that a myocardial alteration may result in less synchrony between the different myocardial segments. However, this must be confirmed by further studies of large populations of healthy and diseased animals.

Despite a similar velocity pattern during the entire cardiac cycle, the left ventricular myocardial segments governing radial motion moved with significantly different velocities depending on their location. The endocardial segment moved more rapidly than the epicardial segment, resulting in an intramyocardial radial velocity gradient. Similarly, the myocardial velocities decreased significantly from the base to the apex along the left caudal wall, resulting in an intramyocardial longitudinal velocity gradient. Similar radial and longitudinal transmural gradients have been described in humans[9] and healthy dogs.[h,i] In humans, the intramyocardial gradients reflect the regional left ventricular function and have a higher sensitivity to pathologic changes than isolated velocity values.[12,14,15] In a model of dilated cardiomyopathy in dogs, these myocardial velocity gradients have recently been found to accurately detect subtle subclinical myocardial dysfunctions.[c,d] The potential relevance of these gradients for identification of early changes in wall motion in cats requires further investigation in cats with cardiomyopathies.

Our results indicate that a positive correlation existed between most myocardial velocities and heart rate. However, because the heart rate did not vary significantly during the entire study, the within-day and between-day variability results could not be explained by heart rate variations.

Before any diagnostic technique can be recommended for clinical use, it must be validated. Unfortunately, few authors have considered the importance of validation during development of new diagnostic imaging techniques, such as echocardiography, for use in cats.[16] Validation is required to determine the meaning of values obtained during an examination. Optimal diagnostic techniques require accuracy, precision (ie, repeatability and reproducibility), specificity, and sensitivity. Accuracy of the TDI technique (ie, the ability to determine accurately the value of myocardial velocities) cannot be tested because there is no reference technique for those in vivo noninvasive measurements. Repeatability and reproducibility are also important because, in clinical use, repeated measurements are performed over the duration of the myocardial disease. Results of our study indicated that both radial and longitudinal left ventricular motions may be quantified in awake cats with adequate within and between-day variability for most myocardial segments, except the apex. By comparison with TDI CV values, the between- and within CV values of conventional echocardiographic parameters in awake cats are slightly lower (between 10% and 20% for most parameters).[17] The highest CV values were observed for the apical segment; maximal CV values of repeatability and reproducibility for systolic wave S and diastolic wave E were 48% and 74%, respectively. The poor results obtained for S and E waves in the apical segment may be partially explained by the low velocity values (approx 2 to 5 mm/s for both S and E) leading to a higher intermeasurement variability. Moreover, in long axis 4-chamber views, the apex may sometimes not be entirely seen at the top of the sector image, and this may be another factor that affected the data obtained for the apical segment. Consequently, measurements of apical myocardial velocities are not reliable in cats, at least not with the technique used in this study. Nevertheless, in other segments, a variation between 2 consecutive measurements smaller than the CV observed here cannot be biologically interpreted. For example, because the CV values of reproducibility were 13.6% and 39.9% for diastolic E wave in the endocardial and epicardial segments, respectively, a 25% decrease for E wave in the epicardial segment may only be caused by variability of the technique, whereas the same decrease may be clinically interpreted in the endocardial segment.

Because TDI measurements obtained from cats with cardiomyopathies are required, sensitivity and specificity of TDI for diagnosis of myocardial diseases could not be determined in the study reported here. Such studies performed in cats with cardiomyopathies will also permit determination of the cutoff values for each TDI velocity in each myocardial segment, which would help to distinguish healthy cats from those with myocardial disease. Use of the data generated from our study will be helpful when considering the potential consequences of within- and between-day variability on the clinical interpretation of TDI measurements in cats with myocardial disease.

Another factor of variation that was not assessed in the study reported here is the effect of the investigator on the measurements. The level of experience of the investigator was found to have a considerable influence on the values of echocardiographic variables in cats.[17] To the authors' knowledge, the study reported here is the first to provide data on repeatability and reproducibility of radial and longitudinal left ventricular velocities obtained via TDI; however, the results are only valid for the investigator that performed the examinations and cannot be extrapolated to other investigators. Results of studies on interinvestigator variability are not yet known. Further studies in healthy cats are also required to provide reference limits for TDI parameters before recommending use of this new technique for early diagnosis of cardiomyopathies in cats.

[a]Martin L, Vandewoude S, Boon J, et al. Left ventricular hypertrophy in a closed colony of Persian cats (abstr). *J Vet Intern Med* 1994;8:143.

[b]Meurs KM, Kittleson MD, Towbin JA, et al. Familial anterior motion of the mitral valve and/or hypertrophic cardiomyopathy is apparently inherited as an autosomal dominant trait in a family of American Shorthair (abstr). *J Vet Intern Med* 1997;11:138.

[c]Chetboul V, Escriou C, Blot S, et al. Early detection of regional myocardial function alterations in a dog model of dilated car-

diomyopathy by tissue Doppler imaging study (abstr). *Circulation* 2001;104(suppl 17):351.

[d]Chetboul V, Escriou C, Thibaud JL, et al. Antenatal detection of Duchenne's cardiomyopathy by tissue Doppler (abstr). *Circulation* 2002;106(suppl 19):397.

[e]General Electric medical system, Waukesha, Wis.

[f]Echo Pac 5.4 software for System 5, GE-Vingmed Ultrasound, Waukesha, Wis.

[g]Systat, version 10.0, SPSS Inc, Chicago, Ill.

[h]Chetboul V, Athanassiadis N, Carlos C, et al. Quantification of longitudinal left ventricular motion using tissue Doppler imaging: new indices of myocardial function in dogs (abstr). *J Vet Intern Med* 2003;17:399.

[i]Chetboul V, Athanassiadis N, Carlos C, et al. Quantification of radial left ventricular motion in healthy dogs using tissue Doppler imaging: intraday and interday variability (abstr). *J Vet Intern Med* 2003;17:440.

References

1. Richardson P, McKenna W, Bristow M, et al. Report of the 1995 World Health Organization/International Society and Federation of Cardiology Task Force on the definition and classification of cardiomyopathies. *Circulation* 1996;93:841–842.

2. Fox PR. Feline cardiomyopathies. In: Fox PR, Sisson E, Moïse NS, eds. *Textbook of canine and feline cardiology*. 2nd ed. Philadelphia: WB Saunders Co, 1999;621–678.

3. Liu SK, Maron BJ, Tilley LP. Feline hypertrophic cardiomyopathy: gross anatomic and quantitative histologic features. *Am J Pathol* 1981;102:388–395.

4. Tilley LP, Liu S-K. Cardiomyopathy and thromboembolism in the cat. *Feline Pract* 1975;5(5):32–37.

5. Fox PR, Liu SK, Maron BJ. Echocardiographic assessment of spontaneously occurring feline hypertrophic cardiomyopathy: an animal model of human disease. *Circulation* 1995;92:2645–2651.

6. Kittleson MD, Meurs KM, Munro MJ, et al. Familial hypertrophic cardiomyopathy in maine coon cats: an animal model of human disease. *Circulation* 1999;99:3172–3180.

7. Nagueh SF, Bachinski LL, Meyer D, et al. Tissue Doppler imaging consistently detects myocardial abnormalities in patients with hypertrophic cardiomyopathy and provides a novel means for an early diagnosis before and independently of hypertrophy. *Circulation* 2001;104:128–130.

8. Isaaz K, Thompson A, Ethevenot G, et al. Doppler echocardiographic measurement of low velocity motion of the left ventricular posterior wall. *Am J Cardiol* 1989;64:66–75.

9. Uematsu M, Miyatake K, Tanaka N, et al. Myocardial velocity gradient as a new indicator of regional left ventricular contraction: detection by a two-dimensional tissue doppler imaging technique. *J Am Coll Cardiol* 1995;26:217–223.

10. Garcia-Fernandez MA, Zamorano J, Azevedo J. Normal patterns with Doppler tissue imaging. In: Garcia-Fernandez MA, Zamorano J, Azevedo J, eds. *Doppler tissue imaging echocardiography*. Madrid: McGraw-Hill Book Co, 1998;23–44.

11. Jones CJH, Raposo L, Gibson DG. Functional importance of the long axis dynamics of the human left ventricle. *Br Heart J* 1990; 63:215–220.

12. Derumeaux G, Cochonneau O, Douillet R, et al. Comparison of myocardial velocities by tissue colour Doppler imaging in normal subjects and in dilated cardiomyopathy. *Arch Mal Coeur Vaiss* 1997;90:773–778.

13. Gavaghan BJ, Kittleson MD, Fisher KJ, et al. Quantification of left ventricular diastolic wall motion by Doppler tissue imaging in healthy cats and cats with cardiomyopathy. *Am J Vet Res* 1999;60: 1478–1486.

14. Garot J, Diebold B, Derumeaux G, et al. Comparison of regional myocardial velocities assessed by quantitative 2-dimensional and M-mode color Doppler tissue imaging: influence of signal-to-noise ratio of color Doppler myocardial images on velocity estimators of the Doppler tissue imaging system. *J Am Soc Echocardiogr* 1998;11:1093–1105.

15. Tsutsui H, Uematsu M, Yamagishi M, et al. Usefulness of the subendocardial myocardial velocity gradient in low-dose dobutamine stress echocardiography. *Heart Vessels* 2000;15:11–17.

16. Moise NS, Horne WA, Flanders JA, et al. Repeatability of the M-mode echocardiogram and the effects of acute changes in heart rate, cardiac contractility, and preload in healthy cats sedated with ketamine hydrochloride and acepromazine. *Cornell Vet* 1986; 76:241–258.

17. Chetboul V, Concordet D, Pouchelon JL, et al. Effects of inter- and intra-observer variability on echocardiographic measurements in awake cats. *J Vet Med A Physiol Pathol Clin Med* 2003;50: 326–331.