ASSESSMENT OF CARDIAC CHAMBER SIZE USING ANATOMIC M-MODE

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Anatomic M-mode (AMM) is an echocardiographic technique that is capable of generating M-mode studies from two-dimensional (2D) cine loops. Unlike conventional M-mode (CMM) whose scan line must lie along the axis of the ultrasound signal, AMM produces M-mode studies independent of the orientation of the ultrasound beam. We sought to determine the ability of AMM to measure cardiac dimensions in normal dogs and to assess the accuracy and variability of AMM and CMM vs. 2D measurements. Thirty-eight healthy dogs underwent physical exam and 2D, CMM, and AMM echocardiographic studies. The end-diastolic and end-systolic dimension of the left ventricle and the diameter of the left atrium (LAD) and aortic root were evaluated from the right parasternal short- and long-axis views. Results of the AMM and CMM study were compared with the 2D study via linear regression and calculation of a coefficient of correlation. AMM increased the level of correlation with both the left ventricular dimensions and LAD. Bland–Altman analysis revealed that AMM increased the level of agreement with 2D measurements and CMM greatly underestimated LAD vs. AMM. In healthy dogs, cardiac AMM measurements are associated with greater accuracy and less variability than CMM. AMM has the potential to improve quantification of cardiac dimensions. *Veterinary Radiology & Ultrasound, Vol. 46, No. 4, 2005, pp 331–336.*

Key words: cardiac mensuration, cardiac ultrasound, echocardiography.

Introduction

M-MODE ECHOCARDIOGRAPHY IN many regards is regarded as "old" technology, particularly in light of high frame rate two-dimensional (2D) imaging, harmonic tissue imaging, and real-time 3D imaging. The benefits of M-mode imaging involve high temporal and axial resolution and ability to clearly delineate the endocardial–blood pool interface.[1] The primary disadvantage of M-mode involves its fixed alignment with the direction of the ultrasound beam. The line of M-mode analysis originates from the apex of the sector scan and runs parallel with the direction of the ultrasound beam, thereby preventing the study of cardiac structures from alternate spatial directions.

Anatomic M-mode (AMM) is a postprocessing technique that creates M-mode studies from stored 2D cine loops and has the capacity to render studies from multiple orientations. The examiner positions the cursor along the desired line of interest and the M-mode study is generated by reading the corresponding 2D pixel intensity throughout the entirety of the cine loop. By generating the AMM study from stored 2D digital data, the examiner is free to position the study along any desired spatial orientation. Inasmuch as the AMM study reflects the quality of the 2D image, advances in ultrasound technology, such as high frame rate 2D imaging, expanded digital cine memory, and powerful computer processing algorithms, have made high-quality AMM studies possible.

Proper alignment of the ultrasound study with the spatial orientation of the left ventricle (LV) is required for accurate measurement of cardiac dimensions. Accordingly, accurate measurement of the internal dimension of the LV from the right parasternal views demands that the line of M-mode study be perpendicular to the long axis of the heart. To achieve this orientation, M-mode studies are typically guided by reference to a simultaneously obtained 2D image, but ideal alignment is not always possible because of individual thorax conformation, interference from lung or ribs, or a limited cardiothoracic window. We hypothesized that AMM, by virtue of its independence from the sector scan origin, could be better aligned with the true internal diameter of the LV, reduce variability of measurement, and have better correlation to measurements made directly from the 2D image. Accordingly, we performed AMM and conventional M-mode (CMM) studies of the LV, left atrium (LA), and aorta in normal dogs and determined the correlation of these measurements to those made directly from the 2D ultrasound image.

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Preliminary results of this manuscript were presented in abstract form at the 21st ACVIM Forum, Charlotte, NC, June 4–7, 2003.

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Received August 31, 2004; accepted for publication January 24, 2005.
doi: 10.1111/j.1740-8261.2005.00062.x

Materials and Methods

Dogs presenting to the Cardiology Service of the Veterinary Teaching Hospital of the University of Illinois were

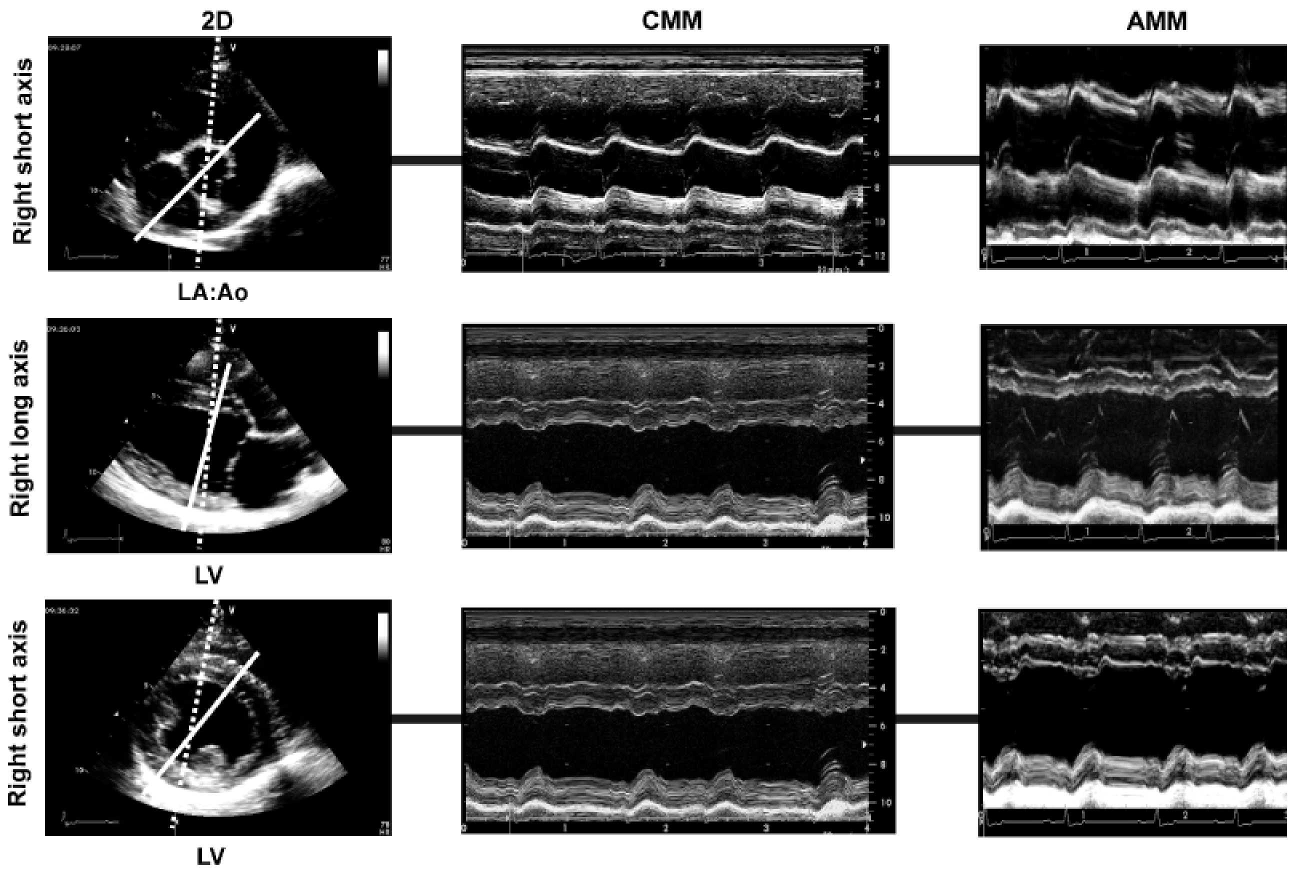

FIG. 1. The orientation of the left atrial (LA), aortic root (Ao), and left ventricular (LV) chamber measurements made from two-dimensional (2D), conventional M-mode (CMM), and anatomic M-mode (AMM) studies is displayed. The line of CMM study is represented by the dashed line, and the line of 2D and AMM study is represented by the solid line. By virtue of its independence from the apex of the 2D sector scan, the line of AMM study can be oriented across the main body of the LA and perpendicular to the long and short axes of the LV. The image quality of the AMM studies is similar to that of the CMM studies with regard to acuity and detection of the endocardial–blood pool interface.

eligible for the study. In addition, healthy dogs were recruited from the hospital staff and students. Enrollment criteria included normal physical examination, 10-lead ECG, and echocardiogram. Echocardiograms were performed using one of two commercially available ultrasound units equipped with AMM software packages.* Patients were restrained in right lateral recumbency on a plexiglass ultrasound table with cut-out panels that allowed the operator to image from the dependent (right) side. Transducer frequency, machine gain, compression, and use of second harmonic tissue imaging were adjusted to obtain optimal 2D images, and were then left unchanged for the duration of the study. Echocardiographic images of the LV, LA, and aortic root were obtained and measured in accordance with previously reported recommendations.[2,3] Standard M-mode studies of the internal dimension of the LV at end-diastole (LVDd) and end-systole (LVDs) were recorded from the right short axis and right long axis parasternal views. From the right short axis view, the diameter of the aorta (AoD) and LA (LAD) was determined at the onset of the electrocardiographic P wave at the level of the aortic valve leaflets. M-mode images were stored in an optical disc. In addition, two separate 2D studies of the LV, LA, and aortic root were recorded. AMM images were generated from one set of digital 2D cine loops using a PC or Macintosh computer running GE/VingMed EchoPAC system software.† AMM studies were produced by positioning an electronic cursor through the desired 2D imaging plane. Unlike CMM, the anterior portion of the AMM cursor line can be ‘‘unhinged’’ from the origin of the ultrasound beam and aligned across the cardiac chamber in a position that approximates an axis perpendicular to the long or short axis of the heart, and bisects the ventricular chamber. Once the cursor line is positioned, the stored digital data are reconstituted over a temporal axis and displayed as a trace that is similar to the CMM study (Fig. 1). From the second set of 2D images, LVDd, LVDs, AoD,

*System V or VIVID 7, GE Medical Systems, Waukesha, WI.

†VIVID 7 EchoPac software version 2.0.0; System V EchoPac software version 6.2, GE Medical Systems, Waukesha, WI.

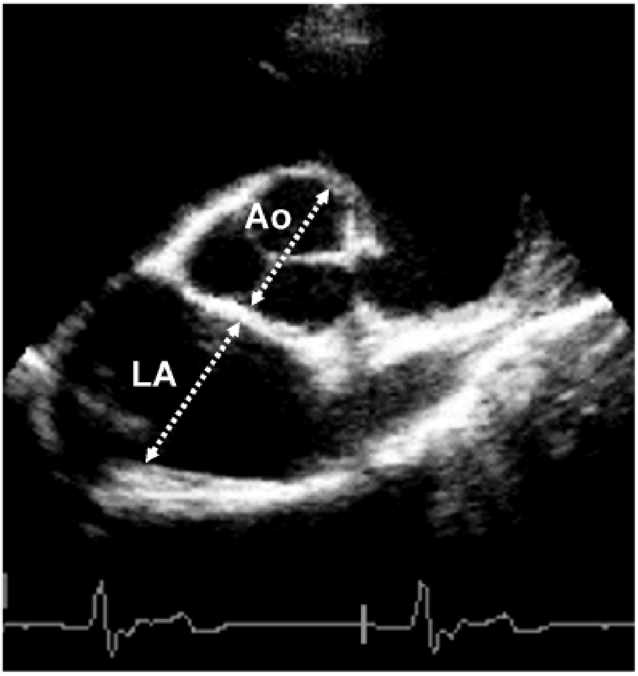

FIG. 2. Two-dimensional echocardiographic measurement of the left atrial and aortic root (Ao) diameter was performed from the right parasternal short-axis view. The diameter of the Ao was measured along a line extending from the middle of the right coronary sinus of Valsalva to the commissure of the left and noncoronary aortic valve leaflets from inner edge to inner edge of the aortic wall. The diameter of the main body of the left atrium (LA) was made along a line that extended from the Ao measurement from inner edge to inner edge of the left atrial wall.

and LAD values were obtained through direct spatial appreciation of the short or long axis of the heart and placement of electronic calipers directly over the 2D images. These 2D-derived dimensions were measured from inner edge to inner edge.[4] In the case of LAD and AoD, measurements were performed to include the widest portion of the main body of the atrium, which usually coincided along a line extending from between the left and noncoronary cusps of the aorta (Fig. 2).[5] All M-mode, AMM, and 2D measurements were performed in triplicate and the resultant average used for comparison between the different techniques. Echocardiographic measurements were imported into PC-based statistical software‡ and M-mode and AMM results were compared with 2D values using linear regression, calculation of the coefficient of correlation (R), and Bland–Altman analysis.[6] Intraobserver coefficients of variability (CV = 100% × SD/mean) were calculated using the measurements from all dogs generated by one observer (M.A.O.). Interobserver coefficients of variability were calculated from a subgroup of eight randomly selected dogs that underwent examination and measurement by two different observers (M.A.O., D.D.S.). The average CV values obtained from CMM and AMM techniques were compared using unpaired t-tests. P-values <0.05 were considered significant. Data are reported as mean ± SEM.

‡Prism v.3.0, GraphPad Software, San Diego, CA.

Results

Patient Population

Thirty-eight dogs were evaluated prospectively and are described by the following signalment data: gender, 20 males, 18 females; age, 5.3 ± 0.6 years; weight, 22.7 ± 2.2 kg. Within this group were 19 mixed breed dogs, four Labrador retrievers, three Doberman pinschers, two Irish wolfhounds, two Dachshunds, and one of each of the following: Beagle, Chihuahua, Cocker spaniel, German shepherd, Pug, Standard poodle, Yorkshire terrier, and English Springer spaniel.

Echocardiography

M-mode and AMM measures correlated well with 2D values (Table 1). For LVDd, LVDs, and LAD measurements, degree of correlation was greater using AMM vs. CMM. Based on Bland–Altman analysis and the resultant SD and 95% confidence intervals (CIs), AMM provided a superior level of agreement with 2D values when performing measurements of the LV from either the short or long axis orientations (Table 2, Fig. 3). With regard to LAD and AoD, CMM tended to underestimate LAD, AMM to overestimate LAD, and both conventional and AMM tended to overestimate AoD. Linear regression between M-mode and 2D measurements of LAD revealed that the slope of the CMM regression was significantly different from the line of unity, and tended to underestimate LAD as the diameter increased (slope, 0.696; 95% CI = 0.507–0.846; vs. unity, $P = 0.0002$) (Fig. 4). In contrast, the slope of the regression line comparing AMM vs. 2D

TABLE 1. Linear Regression Equations and Coefficients of Correlation (R) Describing the Relationship Between 2D and M-Mode Measurements of the Left Ventricle, Left Atrium, and Aortic Root in 38 Healthy Dogs

	CMM		AMM	
	Regression Equation	R	Regression Equation	R
Short axis view				
LVDd	$y = 0.948x + 0.194$	0.965	$y = 0.945x + 0.167$	0.981
LVDs	$y = 0.937x + 0.186$	0.959	$y = 0.979x + 0.130$	0.972
LAD	$y = 0.678x + 0.552$	0.808	$y = 1.072x + 0.107$	0.865
AoD	$y = 1.023x + 0.225$	0.935	$y = 1.061x + 0.182$	0.912
Long axis view				
LVDd	$y = 0.945x + 0.180$	0.971	$y = 0.914x + 0.208$	0.975
LVDs	$y = 1.065x - 0.111$	0.959	$y = 1.028x - 0.048$	0.962

The level of agreement between the 2D and AMM measurements is greater for five of the six parameters measured. LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; LAD, left atrial dimension; AoD, aortic root dimension; 2D, two dimensional.

TABLE 2. Results of Bland–Altman Analysis Comparing Cardiac 2D Measurements with CMM and AMM Values Are Displayed

Parameter	Method	Mean Difference (cm)	SD	95% Confidence Limits
Short axis view				
LVDd	CMM	0.008	0.243	−0.478 to 0.494
	AMM	−0.030	0.180	−0.390 to 0.330
LVDs	CMM	0.030	0.487	−0.944 to 1.004
	AMM	0.077	0.299	−0.521 to 0.675
LAD	CMM	−0.262	0.468	−1.198 to 0.674
	AMM	0.292	0.487	−0.682 to 1.266
AoD	CMM	0.270	0.216	−0.162 to 0.702
	AMM	0.302	0.267	−0.232 to 0.836
Long axis view				
LVDd	CMM	0.008	0.217	−0.426 to 0.442
	AMM	0.086	0.207	−0.328 to 0.500
LVDs	CMM	0.050	0.229	−0.408 to 0.508
	AMM	0.021	0.190	−0.359 to 0.401

In all instances the 95% CIs cross zero indicating a nonsignificant bias. However, as evidenced by the smaller SD and narrower CIs, the level of agreement is greater for AMM than for CMM for measurements of the left ventricle. LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; LAD, left atrial dimension; AoD, aortic root dimension; CMM, conventional M-mode; AMM, anatomic M-mode; SD, standard deviation; CI, confidence interval.

LAD measurement was not significantly different from unity (slope, 1.072; 95% CI = 0.858−1.285; vs. unity, $P = 0.49$).

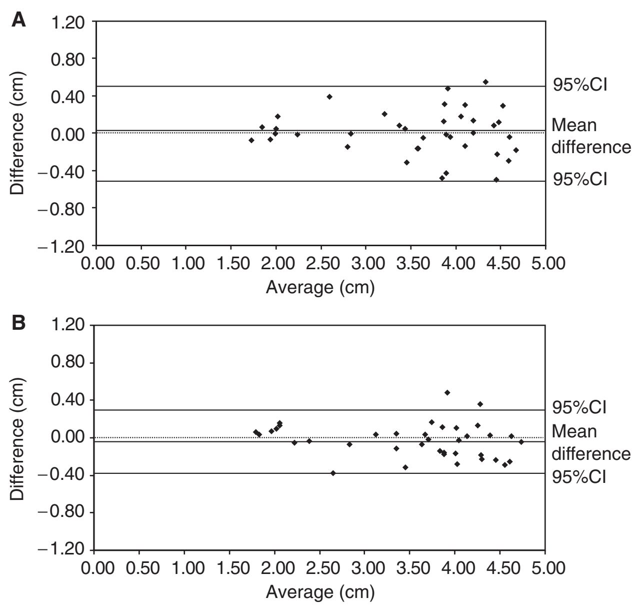

FIG. 3. Bland–Altman plots of the short-axis-derived end-diastolic left ventricular internal dimension comparing measurements made with (A) conventional M-mode (CMM) vs. those made with (B) anatomic M-mode (AMM). The average value of the two-dimensional (2D) and M-mode measurement and the difference between the two measurements are displayed on the *x* and *y* axes, respectively. The mean difference between the measurements is displayed as a solid line and is bounded by the 95% confidence intervals (CIs). The level of agreement between the 2D and AMM values is greater than that of the CMM and 2D values as evidenced by the narrower CIs, and was the case in four of the six echocardiographic parameters measured.

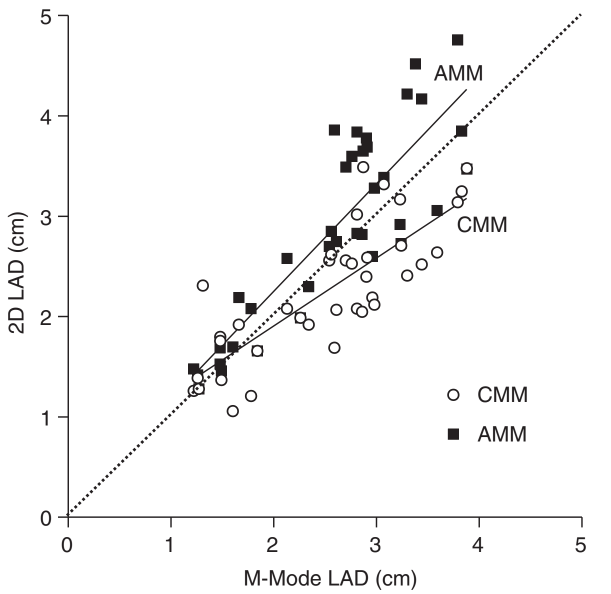

FIG. 4. Comparison of linear regression plots showing the measurement of left atrial diameter (LAD) via conventional M-mode (CMM) and anatomic M-mode (AMM) vs. two-dimensional (2D) values. The slope of the CMM regression is significantly different from the line of unity (dotted line) ($P = 0.0002$) and indicates an increasing bias to underestimate LAD as LAD values increase. In contrast, the slope of the AMM line is not significantly different from the line of unity ($P = 0.49$).

Variability

The intraobserver and interobserver CVs of the two M-mode techniques were relatively low (<6%) and statistically identical to each other (intraobserver, CMM CV = 4.2 0.3% vs. AMM CV = 4.4 ± 0.3%, $P = 0.60$; interobserver, CMM CV = 5.6 ± 1.3% vs. AMM CV = 4.8 ± 0.8%, $P = 0.59$).

Discussion

Our results indicate that AMM quantifies the dimensions of the LV and LA with a degree of accuracy and precision that is superior to CMM. AMM, by virtue of its independence from the point of origin of the ultrasound beam, can be aligned from direct spatial recognition of the heart's orientation around the long or short axis. This allowed the consistent placement of the M-mode cursor along a line that was perpendicular to the axis of the heart. This ability improved correlation to the 2D measurements, which are also based on direct visualization. The most striking difference between conventional and AMM results involved measurement of LAD, and was again because of the ability of the operator to align the AMM cursor across the widest portion of the left atrial body as opposed to the measurement of the left atrial appendage that frequently results from CMM. Both M-mode techniques resulted in the overestimation of AoD compared with 2D, a result that is likely because of the inner edge to inner edge

2D measurement technique that does not include the anterior wall of the aorta, as with either M-mode technique.

In the current study, the image quality of AMM studies was high and approximated the visual acuity of CMM studies. Conventional studies benefit from the high pulse repetition frequency available for interrogation. The pulse repetition frequency (as high as 5000 pulses/s) provides a high degree of temporal and axial resolution that is ideal for study of mobile cardiac structures.[1] AMM studies are derived from the 2D cine loop and are affected by the limitations of 2D echocardiography, namely lower resolution and frame rates as compared with CMM; however, new advances in digital ultrasound technology have narrowed the divide between these two imaging modalities. New transducer and digital imaging technology has increased pulse repetition frequency and resultant 2D frame rates from values around 30 frames/s (fps) to as high as 250 fps depending on the sector scan angle. High PRF increases the density of data gathered and permits the reconstruction of visually pleasing images even when these data are divided among many fps. In our laboratory, 2D study of dogs is typically performed using second harmonic imaging and at frame rates ranging from 60 to 120 fps, yielding a temporal resolution between 8 and 17 ms. AMM studies are constructed from data stored in the machine's digital vector memory, and by extracting the raw digital data prior to analog conversion for display on the video screen, the AMM study is privy to the high data density and high frame rates of newer digital machines.[7]

All of the 2D studies performed in the present report utilized second harmonic tissue imaging. Harmonic imaging transmits a single fundamental frequency (f_0), but only receives and constructs an image based on tissue-generated waves of the second harmonic ($2f_0$). Because harmonic frequencies are generated primarily by tissue structures on the ultrasound beam axis and less so by off-axis structures or structures near the body wall, artifact is reduced and image clarity is significantly improved.[8] The enhanced conspicuity of the endocardial–blood pool interface in harmonic imaging studies translates into a high-quality AMM image. Although we did not specifically attempt to examine the influence of harmonic imaging on image quality, previous studies have demonstrated the superiority of harmonic-generated AMM studies vs. those based on the fundamental frequency.[9,10]

Study Limitations

The current study only involved healthy dogs, and the use of AMM in patients with cardiac disease was not determined. Cardiac disease causes change in chamber dimensions and geometry (i.e., the increased sphericity of the LV in patients with dilated cardiomyopathy), and the ability to guide orientation of M-mode study would be advantageous. We hypothesize that AMM would also be useful in assessing patients with regional dyskinesis or hypertrophy in regions that cannot be aligned perpendicular to the beam axis.

The resolution of the AMM study is affected by the angle of study, and as the angle approaches 90° to the ultrasound beam axis, the lateral resolution of the 2D study (i.e., the ability to discern structures side-by-side perpendicular to the beam axis) becomes the predominant factor in image quality. Because the lateral resolution of 2D studies is less than the axial resolution (i.e., the ability to discern structures head-to-tail along the beam axis), the accuracy of the AMM study suffers once the angle of study exceeds 60° from the direction of the ultrasound beam.[9] In these instances, the AMM study overestimates structure size and displays objects as being closer to the transducer than they actually are. While we did not specifically record the AMM study angle, the amount of divergence from the ultrasound beam was subjectively small during measurement of the LV chamber dimensions (Fig. 1). In the case of LAD and AoD measurement, where the angle was more obtuse, it is possible that apparent structure diameter was affected, and this may have contributed to the AMM overestimation of LAD and AoD. Using an AMM angle of study no greater than 30° has been recommended; however, acquisition of 2D loops using harmonic tissue imaging may permit use of greater angles.[9]

ACKNOWLEDGMENTS

The authors would like to thank Drs. Barret J. Bulmer and Robert Prosek for their assistance.

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