Real-Time Three-Dimensional Echocardiographic Quantification of Left Ventricular Mass: Comparison with Magnetic Resonance Imaging

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Abstract

The accuracy of M-mode and 2D echocardiographic measurements of LV mass is limited. We hypothesized that real-time three-dimensional (RT3D) imaging may allow more accurate measurements. LV mass was calculated from 2D and RT3D images obtained in 21 consecutive patients. The RT3D data resulted in LV mass that correlated with cardiac magnetic resonance measurements better (r=0.90) than 2D (r=0.79). The 2D technique underestimated LV mass (bias 39%). RT3D showed only minimal bias (3%), and reduced the inter-observer (37% to 7%) and intra-observer (19% to 8%) variability. RT3D imaging provides the basis for accurate and reliable measurement of LV mass.

1. Introduction

Left ventricular (LV) mass is an important predictor of morbidity and mortality, especially in patients with systemic hypertension [1]. While echocardiography is most commonly used to evaluate LV mass from M-mode or 2D images, the accuracy of these techniques is limited [2]. The M-mode measurements of LV mass are confounded by their one-dimensional nature, which mandates geometric modeling. The 2D measurements of LV mass rely on the ability to image anatomically correct apical views, which in many patients is compromised by limited access to the apex through the inter-costal spaces. This difficulty is commonly compensated for by acquiring foreshortened views of the ventricle, which result in underestimated area and length and consequently LV mass measurements.

Three-dimensional imaging appears as a potential alternative for accurate evaluation of LV mass, which can be measured directly from the 3D datasets without geometrical modeling [3;4]. Previous studies have demonstrated the feasibility of this approach from 3D data reconstructed from consecutive multiplane acquisitions [5-7]. The recent development of real-time 3D (RT3D) imaging technology is especially appealing since it can potentially allow near on-line quantification of LV volumes and mass without the need for tedious reconstruction.

We hypothesized that RT3D datasets could be used to provide fast and reliable estimates of LV mass, which would be more accurate than those measured using conventional 2D techniques. To test this hypothesis, we compared LV mass values obtained in a group of patients from 2D apical views and those obtained from anatomically correct, nonforeshortened apical views selected off-line from RT3D datasets against the current standard for LV mass values obtained from cardiac magnetic resonance (CMR) images.

2. Methods

Twenty-one consecutive patients (age 48±16 years, 13 men, 8 women) referred for CMR imaging, were studied. Exclusion criteria were: cardiac arrhythmias, left bundle branch block, prior sternotomy, pacemaker or defibrillator implantation, claustrophobia and other known contraindications to MR imaging. Echocardiographic 2D and RT3D imaging was performed on the same day as the CMR study.

2.1. CMR assessment of LV mass

CMR images were obtained using a 1.5 Tesla scanner (General Electric) with a phased-array torso coil. Steady-state free-precession dynamic gradient-echo cine-loops were obtained during 12 sec breath-holds at 20 frames per cardiac cycle. In all patients, 6 to 10 short-axis cine-loops were obtained from base to apex (9 mm slices, no gaps).

Images were analyzed off-line using commercial software (MASS Analysis). In every slice, endocardial and epicardial contours were manually traced at end-diastole, including the papillary muscles in the LV cavity. The traced contours were used to calculate the LV mass, which served as the reference for comparisons against 2D and RT3D echocardiographic data.

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2.2. 2D assessment of LV mass

2D harmonic imaging was performed using a commercial ultrasound system (SONOS 7500, Philips) with an S3 transducer. Images were acquired at held respiration from apical 2- and 4-chamber (A2C and A4C) views, while taking care to avoid foreshortening, and stored digitally for off-line analysis (EnConcert, Philips). In each view, endocardial and epicardial contours were traced including the papillary muscles in the LV cavity (fig. 1, top). The points of insertion of the mitral leaflets into the annulus were connected by a straight line, and the LV long axis dimension was measured as the distance between the center of this line and the most distal point at the apical endocardium. The traced contours were used to calculate endocardial and epicardial LV volumes, using the Simpson's formula [8]. Difference between the epicardial and endocardial volumes was computed for each view and multiplied by 1.05 g/ml to represent a biplane estimate of LV mass.

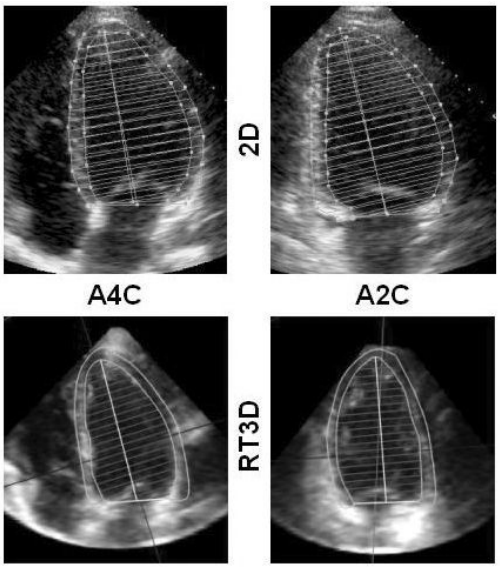

Figure 1. Top: End-diastolic apical 4- and 2-chamber views of the left ventricle obtained in a patient using conventional 2D imaging. Bottom: End-diastolic, anatomically correct apical views selected off-line from a RT3D dataset obtained in the same subject. Manually traced endocardial and epicardial boundaries were used to calculate LV mass (see text for details).

2.3. RT3D assessment of LV mass

RT3D imaging was performed using the matrix array transducer (X4, 2-4 MHz), which utilizes ~3000 elements to obtain a pyramidal volume dataset from a single window. RT3D datasets were acquired using the wide-angled acquisition (93°x80°) mode, in which 4 wedge-shaped sub-volumes (93°x20° each) were obtained from 4 different cardiac cycles during held respiration.

The RT3D datasets were analyzed using commercial software (3DQ-QLab, Philips). The volume data (fig. 2, bottom right) was displayed in 3 cross-sections, which could be modified interactively. The anatomically correct apical views were selected as follows. First, the orientation of the long axis of the 2-chamber view (fig. 2, top right) was determined by positioning a line along the LV long axis in the 4-chamber view (fig. 2, top left). Then, the orientation of the long axis of the 4-chamber view was determined by positioning a line along the LV long axis in the two-chamber view. Then, the mid-papillary short axis plane (fig. 2, bottom left) was defined by positioning two lines in both apical views at the mid-papillary level, perpendicular to the long axis of the ventricle determined in the previous two steps. The final selection of the apical views was achieved by changing the position of the lines in the short axis view: one line was forced to pass near the center of the LV cavity and the most distant point on the right ventricular endocardium; while the other line was forced to pass near the center of the LV cavity perpendicular to the first line. In these two planes, representing the anatomically correct apical views, endocardial and epicardial contours were traced manually at end–diastole while including the papillary muscles in the LV cavity (fig. 1, bottom). The LV long axis dimension was measured the same way as in 2D. The traced contours were then used to calculate LV volumes using the biplane Simpson's formula [8].

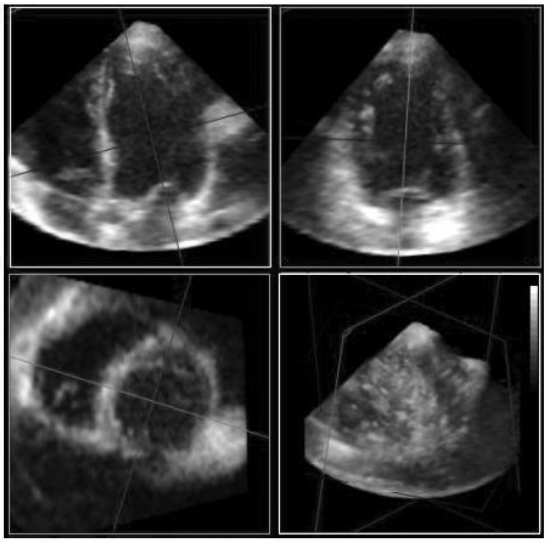

Figure 2. Selection of anatomically correct apical views of the left ventricle (top, left and right) from a real-time

2.4. Inter- and intraobserver variability

To determine the interobserver variability in the 2D and RT3D evaluation of LV mass, all measurements were performed by a second observer. To assess the intraobserver variability, all measurements were repeated one month later by one of the observers. Variability was calculated for each patient as the absolute difference between the repeated measurements in % of their mean.

2.5. Statistical analysis

Agreement between each technique, 2D and RT3D, and CMR was evaluated using paired t-test and linear regression analysis with Pearson's correlation coefficient. Bland-Altman analysis was used to determine the bias and 95% limits of agreement between the echocardiographic and CMR measurements. The differences between LV long axis dimension between the 2D and RT3D techniques were tested using paired t-test. Inter- and intraobserver variability values were averaged for all patients and tested using paired t-test for significance of differences between techniques.

3. Results

Acquisition of RT3D datasets was feasible in all patients except two, whose heart sizes exceeded the pyramidal scan volume. These patients were excluded from analysis. In the remaining 19 patients, the CMR value of LV mass was 126±39 g.

The 2D technique yielded LV mass of 103±39 g by observer #1 and 72±22 g by observer #2, which were significantly lower than the CMR values ($p<0.05$). The combined readings of the two observers resulted in a relatively low correlation with CMR values (figure 3, top left). Bland-Altman analysis (figure 3, bottom left) confirmed the underestimation by the 2D technique by demonstrating a bias of 39 g (39% of the mean) with 95% limits of agreement at ±58 g (±52% of the mean). The LV long axis dimension was 9.2±0.7 cm in the 4-chamber view and 8.9±0.8 cm in the 2-chamber view.

The identification of non-foreshortened apical views from the RT3D datasets was achieved in all 19 patients, in most cases within 20 sec. The RT3D-based technique yielded LV mass of 120±35 g by observer #1 and 123±39 g by observer #2, similar to the CMR values (NS). The combined readings of the two observers resulted in a high correlation with CMR values (figure 3, top right). No significant underestimation by the RT3D-based technique was noted (figure 3, bottom right), as reflected by only a minimal bias of 4 g (3% of the mean) with 95% limits of agreement at ±34 g (±28% of the mean). The LV long axis dimension was 9.4±0.7 cm in the 4-chamber view and 9.4±0.8 cm in the 2-chamber view. These values were significantly larger than the 2D measurements (figure 4).

The interobserver variability was 37±19% of the measured LV mass values for the 2D technique and 7±7% for the RT3D based technique ($p<0.05$). The intraobserver variability was 19±11% of the measured LV masses for the 2D technique and 8±5% for the RT3D based technique ($p<0.05$).

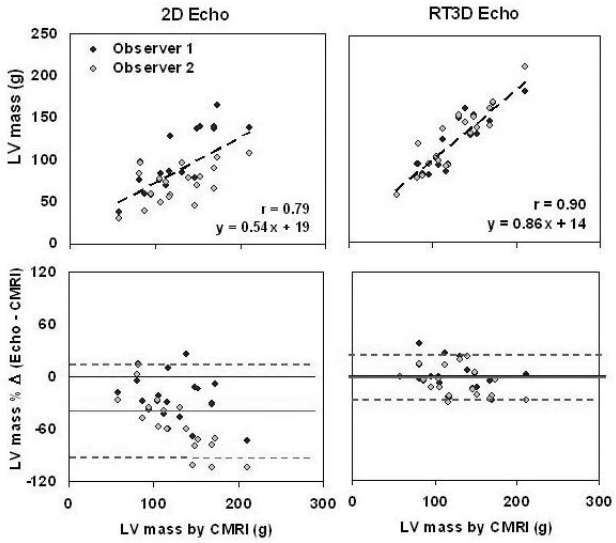

Figure 3. Regression (top) and Bland-Altman (bottom) analyses of LV mass measurements performed in 19 patients from conventional 2D images (left) and RT3D datasets (right) against values obtained from cardiac MRI. Horizontal solid lines represent the mean % difference between each echocardiographic technique and CMR in % of CMR values; dashed lines represent the 95% limits of agreement (±2SD around the mean).

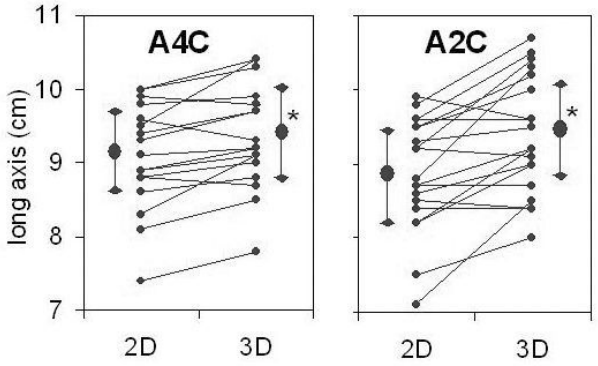

Figure 4. LV long axis dimension measured in 19 patients in apical 4-chamber (left) and 2-chamber (right) views obtained from conventional 2D images and from anatomically correct apical views selected off-line from RT3D datasets. Note the increase in the length of the left ventricle in both apical views, as assessed by the 3D technique in most patients (large circles and error bars represent mean±SD, *$p<0.05$).

4. Discussion and conclusions

Echocardiography has played the leading role in the quantification of LV mass, due to its noninvasive nature, portability and relatively low cost [2]. Several studies have demonstrated that 3D techniques based on off-line reconstruction from multiple planes [3;9-11] were more accurate than the conventional M-mode or 2D methods. In addition, 3D-based techniques were found to be more reproducible and less variable between observers than the conventional techniques [5;12]. Despite these advantages, LV mass measurements from 3D data have not become standard in clinical laboratories, due to cumbersome and time-consuming data acquisition and analysis.

Our goal was to explore the potential of the new RT3D imaging technology for quantitative evaluation of LV mass. We hypothesized that RT3D datasets could allow selection of anatomically correct apical views, which would improve the accuracy of LV mass measurements. We tested this hypothesis by acquiring and analyzing RT3D data in a group of consecutive patients referred for CMR imaging. This study design automatically provided us with validation of our measurements using an accepted standard reference. To allow fair inter-technique comparisons, we used the same bi-plane method of disks to calculate LV mass from 2D images and images selected from the RT3D datasets.

The RT3D estimates of LV mass resulted in higher levels of agreement with the CMR values than the 2D estimates. Our measurements of the LV long axis dimension proved that off-line cross-sectioning of the RT3D datasets provided less foreshortened apical views, thus explaining the improved accuracy of this technique. In addition, our results indicate that the 3D technique provides more reproducible measurements than the conventional 2D technique. The fact that the interobserver variability of the RT3D technique is virtually equal to the intraobserver variability, and both are below 10%, indicates reproducibility that is acceptable for clinical use.

In conclusion, assessment of LV mass from RT3D datasets is feasible in consecutive patients. This technique is more accurate than the conventional 2D methods. It is also fast and relatively free of motion artifacts, compared to previous techniques based on 3D reconstruction from multiple planes. These findings have important clinical implications for the assessment of the severity of LV hypertrophy in patients with systemic hypertension. Also, due to the improved accuracy, reproducibility, speed and ease of use, this technique could potentially reduce the number of patients necessary to achieve standard levels of statistical significance, and thus result in significant savings in future epidemiologic studies aimed at assessing the effects of antihypertensive drugs.

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