Three-Dimensional Echocardiographic Assessment of the Extension of Dysfunctional Mass in Patients with Coronary Artery Disease

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Two-dimensional (2D) echocardiographic estimation of infarcted mass is limited by having only a few selected nonparallel views for data analysis. Volume-rendered three-dimensional (3D) echocardiography may be able to overcome the above limitations, because it uses multiple, parallel 2D images to derive quantitative data. Previous experimental studies demonstrated that 3D echocardiography is an accurate and reproducible method to assess dysfunctional mass. To estimate the accuracy of 3D echocardiography in humans, we evaluated 10 patients who had a single myocardial infarction. All patients underwent 2D and 3D echocardiography using the transesophageal approach, and contrast (gadolinium) magnetic resonance imaging (MRI), considered a reference standard for infarcted tissue detection. The mean extent of dysfunctional mass by MRI was 28 ± 13 g and by 3D echocardiography was 30 ± 12 g; the mean difference was 1.9 ± 2.3 g (p = not significant). Linear regression analysis between the 2 measurements was y = 0.97x − 1.12, r = 0.98. Dysfunctional mass derived from 3D echocardiography reflects the real site and extension of damaged myocardium. ©1998 by Excerpta Medica, Inc.

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Echocardiography has evolved over the last 3 decades from single beam imaging to sophisticated two-dimensional (2D) and Doppler techniques, which allow the study of cardiac structure, function, and hemodynamics in detail. However, an inherent limitation of conventional echocardiography is its ability to depict complex three-dimensional (3D) structures, such as the heart and great vessels, in only 2 dimensions. This implies an incomplete appreciation of the spatial relations between cardiac structures and the use of geometric assumptions to extrapolate quantitative data, particularly when the cardiac chambers are deformed.

The extent of myocardial damage during acute myocardial infarction is the most important determinant of prognosis.[1,2] The 2D echocardiographic estimation of infarcted mass is limited by the use of few selected nonparallel views extrapolated from the whole left ventricle. Dynamic volume-rendered 3D echocardiography has become a practical reality, able to overcome the above limitations, since it utilizes multiple, parallel 2D images to produce quantitative data.[3,4] Previous studies demonstrated that 3D echocardiography is an accurate and reproducible method to assess left ventricular mass and dysfunctional mass in experimentally created infarcted ventricles.[5–7] In this study, we report the preliminary results of a comparative analysis between 3D echocardiography and magnetic resonance imaging (MRI) in the assessment of regional dysfunction mass in patients with ischemic heart disease.

METHODS

The study group consisted of 10 selected patients (all men; mean age 56 ± 7 years) who had a previous and single episode of myocardial infarction. All patients were asymptomatic, without complex cardiac arrhythmias. After a diagnostic examination by conventional 2D echocardiography, all patients underwent 3D echocardiographic examination and MRI with a gadolinium contrast agent for infarcted tissue detection. MRI and 3D echocardiographic studies were performed within 1 week. Informed consent was obtained from each patient.

Instrumentation and 3D echocardiographic data acquisition: A 64-element phased-array echocardiographic system (Sonos 2500; Hewlett Packard, Andover MA, USA), with integrated software able to rotate the ultrasound beam in a predetermined manner was used. The multiplane transesophageal probe was introduced into the esophagus with the patient in the left decubitus position after local anesthetic spray (lidocaine 2%) to the hypopharynx, and general sedation (intravenous diazepam 2.5–10 mg). The probe was positioned at the mid-esophageal portion for image acquisition and was kept stationary during the study. The rotation of the transducer was controlled by the software every 3° through a 0–180° arc, with the reference position corresponding to the 4-chamber view. Electrocardiographic and respiratory gating, automatically provided by the integrated software, were used for spatial and temporal registration of acquired images. A total of 60 sequential cross-sections during a complete cardiac cycle were acquired and transferred onto a laser disk for subsequent postprocessing

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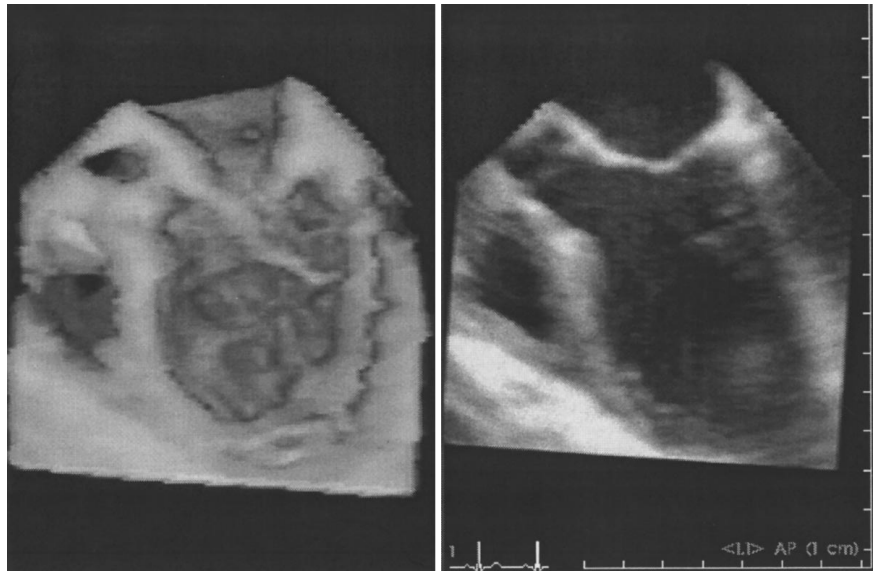

FIGURE 1. Three-dimensional reconstruction of the left ventricle in a 5-chamber projection in a patient with akinesis of the interventricular septum: the endocardium at the level of the lateral wall and apex is well delineated.

and data analysis. For measurement of total left ventricular mass and for calculation of dysfunctional mass, multiple short-axis cross-sectional views were electronically segmented into 12–15 equidistant slices (5 mm in slice distance) from the apex to the mitral annular level (Figure 1). For determining left ventricular mass, the myocardium of the left ventricle on each transverse slice was countered and labeled. By integrating the slice thickness with the slice area, the volume of each slice and the total volume of all myocardial slices were computed in an automated manner by a new quantification algorithm. Myocardial mass volume multiplied by assumed specific gravity (1.05 g/mL) provided myocardial mass (weight in grams). For measurement of dysfunctional myocardium mass, the following steps were performed: each short-axis 2D slice extracted from the 3D data set was viewed in a dynamic fashion. In these images, regional wall motion abnormalities were clearly evident. The segments that exhibited discrete hypokinesis, akinesis, or dyskinesis were demarcated. These segments were countered and labeled. The volume of the dysfunctional myocardial segments (the labeled regions) was provided automatically by the computer as mentioned above. Using the specific gravity of the myocardium, the mass of the dysfunctional myocar-

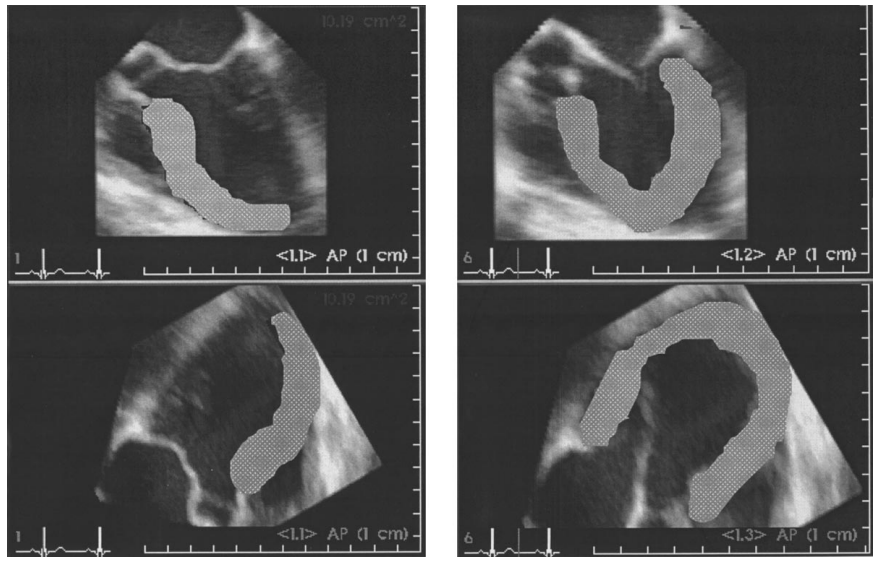

FIGURE 2. Quantitation of total left ventricular mass and regional dysfunctional mass by 3D echocardiography. Delineation and computation of regional dysfunctional mass (*left*) and total left ventricular mass (*right*) by 3D echocardiography. In this example, the total extent of interventricular septum was akinetic.

TABLE I Assessment of Dysfunctional Versus Total Ventricular Mass

Patient Number	MRI DM (gr.)	3DE DM (gr.)	MRI LVM (gr.)	3DE LVM (gr.)	DM 3DE %	DM MRI %
1	12	15	160	145	10	8
2	41	40	170	165	24	25
3	15	18	150	155	12	10
4	28	31	155	175	18	16
5	22	25	155	147	17	15
6	10	11	130	127	9	8
7	37	40	139	137	29	27
8	43	40	122	129	31	33
9	54	60	164	170	35	32
10	21	22	123	140	16	15
Media	28	30	147	149	20	19
DS	13	12	16	17	9	10

3DE DM = extent of dysfunctional mass by three-dimensional echocardiography; 3DE LVM = left ventricular mass by three-dimensional echocardiography; MRI DM = extent of dysfunctional mass by magnetic resonance imaging; MRI LVM = left ventricular mass by magnetic resonance imaging; %DM = percentage of dysfunctional mass detected as a ratio between dysfunctional mass and total left ventricular mass.

dium was generated. From these data, the percentage of the total left ventricular myocardium involved in regional myocardial dysfunction was calculated as well (Figure 2).

Instrumentation and MRI acquisition: Images were obtained from a commercially available 1-Tesla superconducting magnet (Magnetom Impact; Siemens, Erlangen, Germany) with body-array coil. Then, 10–20 minutes after intravenous injection of paramagnetic contrast agent (Gd-DTPA Magnevist; Schering: 0.2 mm/kg), a double-oblique orientation fast GRE (FLASH) single-slice–multiphase technique (TR 5 msec, TE 2.2 msec, flip angle 25°, 128 ×, FOV 350 mm, 10-mm slice thickness) was employed, encompassing the entire left ventricle along its long axis with repeated breath-hold acquisitions (18 sec) of 5 electrocardiographically gated short-axis images for each slice level without interslice gap.

Visual assessment of infarct location was based on the (1) presence of areas with significantly increased signal intensity (intensity ratio >1.4),[8,9] and (2) evidence of wall motion abnormalities on the cineloop view of single-phase, multi-slice, short-axis images. In the presence of apical left ventricle involvement, additional multi-phase long-axis acquisitions were employed to obtain a better definition of apical left ventricle dysfunction. All sets of images were then subjected to quantitative functional analysis by means of a dedicated software package for short-axis MRI (ARGUS; Siemens, Erlangen, Germany). After manual boundary delineation on end-diastolic and end-systolic short-axis magnified images of each level, leaving out the papillary muscles, a center of mass (epicardial centroid floating) was determined by the image processing software, and the left ventricular myocardium was divided clockwise into 12 equally spaced segments by radii generated from the center of the mass, with computerized assessment of segmental end-diastolic wall thickness and absolute systolic wall thickening. To assess interobserver variability with respect to manual boundary tracing, MRI were independently evaluated by 2 experienced observers without knowledge of previous echocardiographic results; measurements were repeated by 1 observer, 1 month after the first evaluation to assess intraobserver variability.

The results of quantitative functional analysis were transferred to the baseline images, summing at each slice level the segmental areas (cm^2) with significant dysfunction (absolute systolic wall thickening <2),[10] then multiplying the obtained value by slice thickness (1 cm) and standard myocardial density (1.05 g/cm^3), thus obtaining the dysfunctional left ventricular mass (grams).

Statistical analysis: 3D measurements were compared with MRI data using simple linear regression analysis and Student's paired *t* test. Difference between 3D echocardiographic and magnetic resonance measurements was evaluated with Bland-Altman analysis.[11] Inter- and intraobserver variability was calculated as the difference between 2 observations divided by the mean values.

RESULTS

Good quality 3D reconstructions were obtained in all patients. The extent of dysfunctional mass by MRI was 10–54 g (mean 28 ± 13 g), and by 3D echocardiography was 11–60 g (mean 30 ± 12 g); the mean difference was 1.9 ± 2.3 g (p = not significant). Linear regression analysis between the 2 measurements was $y = 0.97x - 1.12$; ($r = 0.98$; $p < 0.0001$). Mean left ventricular mass by MRI was 147 ± 16 g (range, 122–170 g), and by 3D echocardiography, 149 ± 17 g (range, 127–175 g); the mean difference between the 2 techniques was 2.2 ± 1.1 g (p = not significant). Linear regression analysis was: $y = 0.8lx + 25.3$ ($r = 0.80$, $p < 0.001$). The mean percent dysfunctional mass by MRI was 19 ± 10% and by 3D echocardiography was 20 ± 9% (p = not significant). Interobserver variability for dysfunctional mass by 3D echocardiography was 5 ± 2%.

DISCUSSION

According to our preliminary results, we can affirm that 3D echocardiography is a feasible and a reproducible method for quantitation of dysfunctional mass

in patients with ischemic heart disease. In fact, we found an excellent correlation between the extent of dysfunctional mass obtained by 3D echocardiography and MRI without significant under- or overestimation. In addition, a high correlation was found between the percentage of left ventricular dysfunctional myocardium calculated by MRI and by 3D echocardiography.

Conventional 2D echocardiography is an established method for noninvasive evaluation of regional myocardial dyssynergy. Clinical and experimental studies[12,13] have demonstrated a clear relation between the site and extent of echocardiographically defined regional dysfunctions and the pathologic evidence of infarction. Unfortunately, quantitative analysis of regional dysfunction is affected by translation and rotation of the heart, respiratory movements, and a relatively poor epicardial resolution of the left ventricle. Using various echocardiographic techniques,[14,15] semi-quantitative analysis is usually extrapolated from a few nonequidistant or nonparallel 2D images (3 short-axis and 1 or 2 apical views) using internal anatomic landmarks as a reference position.

Previous experimental animal studies[5,7] demonstrated that 3D echocardiography is able to overcome the above limitations, since the extent of dysfunctional mass is calculated from multiple parallel views precisely realigned according to a predefined respiratory and electrocardiographic gating. Our results also confirm that 3D echocardiography is an accurate technique for the definition and quantitation of dysfunctional myocardial regions in a clinical setting.

LIMITATIONS

We acknowledge that our results are preliminary and therefore the real feasibility of 3D echocardiography in the clinical scenario needs to be established. Moreover, the assessment of dysfunctional mass was based on visual assessment using both MRI and 3D echocardiography techniques. The 3D examinations were obtained through a transesophageal approach and therefore used a semi-invasive technique, which cannot be, at the moment, widely applied to all patients with ischemic heart disease.

CONCLUSIONS

Our preliminary results demonstrated that 3D echocardiography is able to clearly display and quantify wall motion abnormalities in patients with previous myocardial infarction. The percentage of dysfunctional myocardium can also be assessed, giving important physiologic and clinical information for the treatment of patients with ischemic heart disease.

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