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Comparison of Left Atrial Volume Assessed by Magnetic Endocardial Catheter Mapping Versus Transthoracic Echocardiography

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Increased left atrial (LA) size and volume have been shown to predict a higher risk of recurrent atrial fibrillation (AF) and atrial arrhythmias.¹⁻³ Methods for delineating LA size and volume are of significant clinical importance. The most common technique used for determining LA size in clinical practice is 2-dimensional guided M-mode echocardiography.⁴ Although LA size determined by M-mode echocardiography is most commonly used in clinical practice, it has recently been shown that this technique is the least accurate for determining LA volume.⁵ Two-dimensional transthoracic echocardiography has been established as a reliable technique by which to determine LA volume that correlates closely with volume estimated by cine computed tomography^{6,7} and cine magnetic resonance imaging.⁸ Magnetic electroanatomic mapping (MEAM) creates an anatomic shell of the endocardial surface of the chamber being mapped, and we have previously shown that this technique can be used to determine LA dimension with the same accuracy as 2-dimensional guided M-mode echocardiography.⁹ MEAM uses the current generated by a location sensor at the tip of the mapping catheter to identify the catheter tip at the intersection of 3 low-strength magnetic fields.¹⁰ When the roving catheter is moved in 3-dimensional space, its location relative to a reference placed on the patient's back is continuously monitored with a resolution of <1 mm.¹¹ We hypothesized that the high spatial resolution of MEAM would be able to obtain precise LA volume measurements that were similar to those obtained by 2-dimensional transthoracic echocardiography. An additional method for determining LA volume may prove valuable in those patients with AF who underwent LA mapping and ablation. Creating a 3-dimensional shell of the left atrium using this system has

been reported to facilitate ablation of focal triggers for paroxysmal AF.¹² The purpose of our study was to establish the accuracy of LA volume measurements by MEAM against LA volume measured by 2-dimensional transthoracic echocardiography using the disk method.

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The study group included 57 consecutive patients (46 men) with symptomatic drug-refractory AF who were referred for AF ablation between March 2000 and September 2001. The mean age of the study group was 50 ± 12 years (range 21 to 74). The history of symptomatic AF ranged from 3 to 360 months (mean 51), 52 patients had paroxysmal AF, and 5 patients had persistent AF (>3 months). The median number of failed antiarrhythmic drugs was 4 (range 1 to 7). Left ventricular ejection fraction was normal in 52 patients and mildly depressed (range 40% to 50%) in 5 patients. Echocardiograms were obtained for all patients during the same hospitalization as when the mapping and ablation procedure was performed. The time between the 2 procedures ranged from 0 to 3 days with a median of 2 days.

MEAM was performed using a 7Fr deflectable catheter (CARTO; Webster Biosense Inc., Diamond Bar, California). The catheter was placed in the left atrium using the standard Brockenbrough transeptal technique.¹³ All aspects of the left atrium were mapped in detail during sinus rhythm under the guidance of fluoroscopy and MEAM with sample points acquired during atrial diastole. If the patient was not in sinus rhythm they were either cardioverted, or the map was constructed after the successful ablation of all AF triggers. A mean of 126 ± 37 individual points were acquired (range 78 to 224) with attention to defining the mitral valve annulus, LA appendage, and each of the pulmonary veins in every patient. We were able to define these structures for all patients in the study, including the right lower pulmonary vein, and construction of the LA map took a mean of 28 ± 10 minutes (range 14 to 48). The LA volume was computed by MEAM using the built-in volume computation function of the Biosense system (Figure 1).

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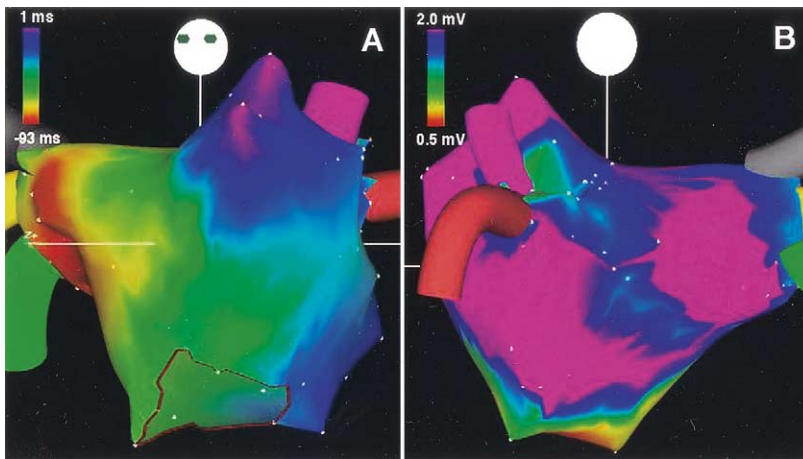


FIGURE 1. Sinus rhythm electroanatomic maps of the left atrium. (A) Complete LA map of a representative patient in the LAO projection at 30° superimposed with the activation times relative to a reference electrode at the os of the coronary sinus. Red represents the earliest activation times and purple represents the latest activation times. (B) Voltage map of the left atrium from the same patient in the straight posteroanterior view. Red represents the lowest recorded voltages (<0.5 mV) and purple represents the largest voltages (>2.0 mV). Note that all major structures and aspects of the left atrium have been recorded on the map, which is constructed from 93 individual points.

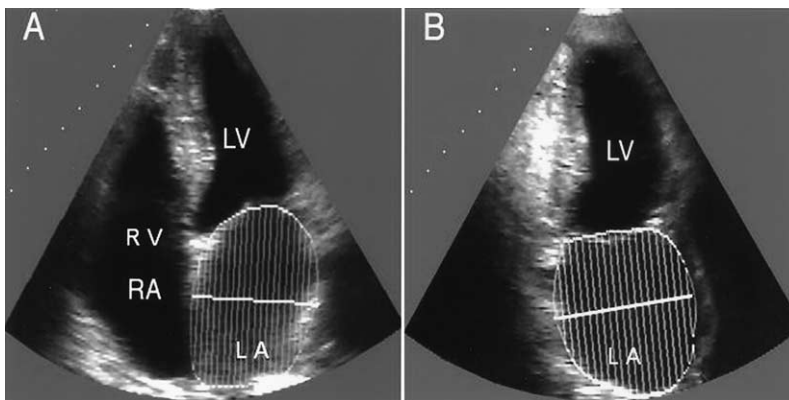


FIGURE 2. Assessment of LA volume by transthoracic echocardiography using the disk method. Two-dimensional echocardiographic images of the apical 4- (A) and 2-chamber (B) views are shown. The left atrial endocardium (LA) was digitally traced, and LA volume was computed using the TomTec workstation software by placing 21 equidistant disks perpendicular to the short axis of the left atrium. LV = left ventricle; RV = right ventricle; RA = right atrium.

Transthoracic 2-dimensional echocardiography was performed in each patient using an S4 transducer with the Sonos 5500 machine (Philips Medical Systems, King of Prussia, Pennsylvania). LA volume was calculated from the 2-dimensional images using the disk method in 2 orthogonal planes. Briefly, the LA endocardium was traced manually at atrial end-diastole (the frame before the mitral valve opening) in the apical 2- and 4-chamber views using off-line analysis on a TomTec workstation (TomTec Medical Imaging, Boulder, Colorado). The workstation software subdivided the 2 endocardial surfaces into 21 equal disks along the short axis of the left atrium. The volume from each view was computed by summing the vol-

ume of the individual disks, and the final LA volume was determined by averaging the volumes from each orthogonal imaging plane (Figure 2). Echocardiographic LA volume measurements were made independently and without prior knowledge of LA volumes determined by MEAM.

Values are reported as mean \pm 1 SD. The correlation coefficient comparing MEAM versus the echocardiographic results was computed using a linear regression model, and a correlation coefficient calculated with a p value <0.05 was considered significant.

LA volume measured by 2-dimensional echocardiography was 93 ± 26 versus 125 ± 28 ml when measured by MEAM. The volume measurements obtained by these 2 techniques correlated well with a high degree of significance ($r = 0.90$, $p < 0.001$), as shown in Figure 3. LA volume measured by transthoracic echocardiography was consistently lower than that measured by MEAM (Figure 4). On average, the LA volume measured by transthoracic echocardiography was 26% lower than that measured by electroanatomic mapping.

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The present report shows that LA volume can be determined by MEAM with volumes comparable to those found by 2-dimensional transthoracic echocardiography. The correlation of LA volumes between the 2 measurement techniques ($r = 0.90$) is comparable to the initial studies validating LA volume determined by 2-dimensional transthoracic echocardiography versus cine computed tomography ($r = 0.88$,⁶ $r = 0.91$).⁷ MEAM has a precision of approximately 1 mm for localizing points in 3-dimensional space,¹¹ so precise chamber

volumes should be achievable. However, MEAM volumetric measurements are influenced by respiratory cycle variation because the reference is on the patient's back, whereas echocardiographic volumetric measurements are not as greatly influenced by bulk respiratory motion. Therefore, respiratory motion will affect the accuracy of MEAM volumetric measurements and potentially lower the correlation between MEAM and echocardiography. In addition, we found that LA volumes determined by echocardiography are 26% lower than those determined by MEAM. Because LA volume determined by echocardiography is similarly underestimated compared with cine computed tomography (23%)⁶ and cine magnetic resonance im-

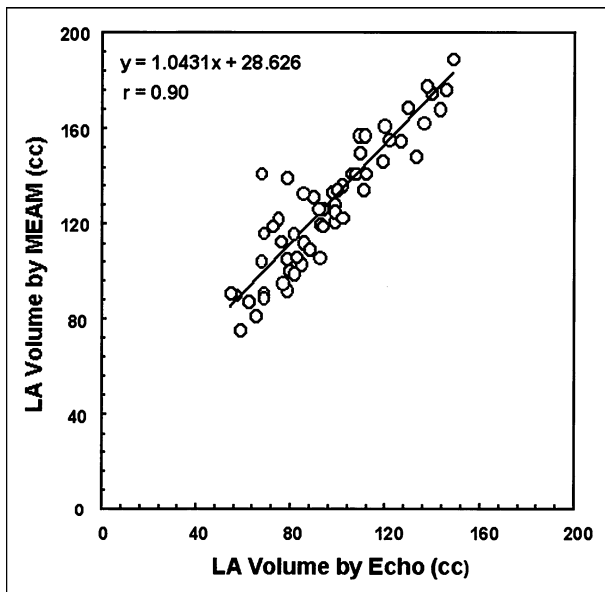


FIGURE 3. The relation between LA volume measured by echocardiography and MEAM for all 57 patients. The straight line is the best fit to the data points as computed by a linear regression model. The correlation of LA volume as assessed by the 2 different measurement methods was good and highly significant ($r = 0.90$, $p < 0.001$). cc = milliliters.

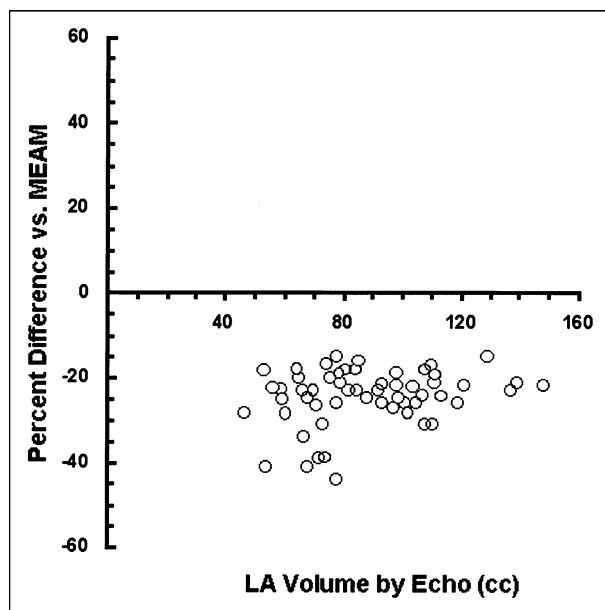


FIGURE 4. Bland-Altman plot of LA volume measured by echocardiography compared with MEAM. Note that echocardiography consistently underestimated LA volume when compared with that measured by MEAM. In most cases, LA volume was approximately 20% to 30% lower when measured by echocardiography compared with that measured by MEAM, but the range varied from 14% to 45%. Abbreviation as in Figure 3.

aging (14% to 37%),⁸ we can indirectly infer that LA volumes determined by MEAM are similar to those determined by cine computed tomography and cine magnetic resonance imaging. One obvious limitation of this study is that all subjects we assessed had drug-refractory AF, without a group of arrhythmia-

free subjects for comparison. Still, this is the first study to establish the spatial accuracy of MEAM for defining cardiac chamber volume.

There are several plausible reasons for 2-dimensional echocardiography underestimating LA volumes. These relate to foreshortening of the atrium and technical difficulties in obtaining 2- and 4-chamber views that are truly orthogonal. Also, because the atria are the cardiac structures farthest away from the transducer in the apical views, the LA walls are transparent to the ultrasound beam with loss of lateral resolution. Systematic errors in planimetry may occur from drop-out of the interatrial septum in the 4-chamber view and the anterior wall in the 2-chamber view. Measurements made from 2-dimensional echocardiography may also exclude volume within intertrabecular spaces.¹⁴ In addition, the higher volume seen with MEAM may be the result of including the volume of the LA appendage with this technique, but excluding it when outlining the endocardium during volume determinations made by echocardiography.^{6,7} Additionally, mapping with a catheter may result in some distention due to catheter tension and this could increase the volume measured by electroanatomic mapping.

Given the high correlation of atrial volume with the incidence of AF,¹ the ability to immediately assess LA volume at the time of ablation may be useful in planning mapping and ablation strategies in patients with an enlarged LA. In addition, for those patients who require repeat procedures, LA volume may be reliably tracked with MEAM during subsequent procedures. This is important because LA volume, as determined by 2-dimensional transthoracic echocardiography, has been shown to increase due to AF.¹⁵ Therefore, increased LA volume may be a marker of uncontrolled AF and prompt more aggressive ablative strategies and/or postablative monitoring and medical therapy.

In summary, LA volume measured by MEAM correlates well with volumes computed by 2-dimensional echocardiography. MEAM appears to be an accurate method by which LA volume can be measured in patients with drug-refractory AF.

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Peripheral Conduction Disease in Left Ventricular Dysfunction

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Several studies have correlated conduction abnormalities on the 12-lead electrocardiogram (ECG) with echocardiographic findings.^{1–3} Echocardiographic studies on left bundle branch block (LBBB) produce variable findings that are related to the underlying cardiac pathophysiology. However, paradoxical septal motion on echocardiography is seen in most and is presumed secondary to abnormal septal activation related to a proximal conduction abnormality. We have previously reported that nonspecific widening of the QRS complex in the absence of typical electrocardiographic criteria for right bundle branch block (RBBB) or LBBB is associated with evidence of left ventricular (LV) dysfunction.⁴ Although the mechanism of QRS widening was unknown, it was hypothesized that increased LV fibrosis in the presence of LV dysfunction led to an intraventricular conduction delay (IVCD), suggesting the presence of peripheral conduction disease. The present report has 3 purposes: (1) to support the existence of peripheral conduction disease by evaluating upper septal motion on echocardiography in patients with typical electrocardiographic criteria for either an IVCD or LBBB—peripheral conduction block was presumed in the presence of normal upper septal motion (no paradoxical septal motion) using echocardiography; (2) to compare LBBB versus IVCD in relation to echocardiographic findings of LV dysfunction; and (3) to compare the LV echocardiographic systolic function in patients with LBBB and paradoxical septal motion in comparison with normal septal motion.

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A retrospective database review was carried out to identify patients with LBBB or an IVCD on the surface 12-lead ECG in whom a concomitant 2-dimensional echocardiogram was performed ≤ 1 month of the ECG. Studies performed between January 1, 1999 and June 30, 2000, at Mary Immaculate Hospital (Queens, New York) were reviewed.

LBBB was coded if all of the following criteria on 12-lead ECG^{5,6} were met: (1) QRS duration of ≥ 0.12 seconds; (2) presence of a broad monophasic R wave, usually notched or slurred, in leads V_5 , V_6 , and I; (3) absence of Q waves in leads I, V_5 , and V_6 ; (4) delay of onset of the intrinsicoid deflection in leads V_5 and V_6 ; and (5) displacement of the ST segment and T wave in a direction opposite to the major deflection of the QRS complex. A left-axis deviation was defined as a frontal axis $< -30^\circ$. Patients with a QRS duration ≥ 0.10 second without criteria for either LBBB or RBBB were classified as having IVCD. Patients with incomplete or complete RBBB, coronary artery bypass surgery or valve replacement, right ventricular volume overload, pacemaker rhythm, or on antiarrhythmic medications that are known to alter QRS duration and/or cause abnormal septal motion on echocardiogram were excluded.

The 2-dimensional echocardiogram of each patient was independently assessed for upper septal motion, estimated ventricular function (ejection fraction), and LV diastolic and systolic dimensions by 2 experienced echocardiographers who were blinded to the surface electrocardiographic findings. A third echocardiographer adjudicated any discrepancy in the analysis of upper septal motion between the 2 echocardiographers. A third echocardiographer was necessary in 18% ($n = 16$) of the cases. Upper septal motion was determined by analyses of appropriate M-mode and 2-dimensional slices of the left ventricle. Ejection

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