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ORIGINAL RESEARCH

# Real-Time 3D Echocardiographic Quantification of Left Atrial Volume

## Multicenter Study for Validation With CMR

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**OBJECTIVES** We studied in a multicenter setting the accuracy and reproducibility of 3-dimensional echocardiography (3DE)–derived measurements of left atrial volume (LAV) using new, dedicated volumetric software, side by side with 2-dimensional echocardiography (2DE), using cardiac magnetic resonance (CMR) imaging as a reference.

**BACKGROUND** Increased LAV is associated with adverse cardiovascular outcomes. Although LAV measurements are routinely performed using 2DE, this methodology is limited because it is view dependent and relies on geometric assumptions regarding left atrial shape. Real-time 3DE is free of these limitations and accordingly is an attractive alternative for the evaluation of LAV. However, few studies have validated 3DE-derived LAV measurements against an accepted independent reference standard, such as CMR imaging.

**METHODS** We studied 92 patients with a wide range of LAV who underwent CMR (1.5-T) and echocardiographic imaging on the same day. Images were analyzed to obtain maximal and minimal LAV: CMR images using standard commercial tools, 2DE images using a biplane area-length technique, and 3DE images using Tomtec LA Function software. Intertechnique comparisons included linear regression and Bland-Altman analyses. Reproducibility of all 3 techniques was assessed by calculating the percentage of absolute differences in blinded repeated measurements. Kappa statistics were used to compare 2DE and 3DE classification of normal/enlarged against the CMR reference.

**RESULTS** 3DE-derived LAV values showed higher correlation with CMR than 2DE measurements ($r = 0.93$ vs. $r = 0.74$ for maximal LAV; $r = 0.88$ vs. $r = 0.82$ for minimal LAV). Although 2DE underestimated maximal LAV by $31 \pm 25$ ml and minimal LAV by $16 \pm 32$ ml, 3DE resulted in a minimal bias of $-1 \pm 14$ ml for maximal LAV and $0 \pm 21$ ml for minimal LAV. Interobserver and intraobserver variability of 2DE and 3DE measurements of maximal LAV were similar (7% to 12%) and approximately 2 times higher than CMR (4% to 5%). 3DE classified enlarged atria more accurately than 2DE (kappa: 0.88 vs. 0.71).

**CONCLUSIONS** Compared with CMR reference, 3DE-derived LAV measurements are more accurate than 2DE-based analysis, resulting in fewer patients with undetected atrial enlargement. (J Am Coll Cardiol Img 2012;5:769–77) © 2012 by the American College of Cardiology Foundation

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It is well established that increased left atrial volume (LAV) is associated with adverse cardiovascular outcomes and is among the first criteria used to diagnose left ventricular (LV) diastolic dysfunction, according to the current recommendations of the American Society of Echocardiography (1). Today, LAV measurements are routinely performed using 2-dimensional echocardiography (2DE). Most commonly, LAV is estimated using either the single- or bi-plane area-length technique

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or method of disks (2). The accuracy of these approximations is limited because of their view dependency and their reliance on geometric assumptions regarding left atrial (LA) shape. In addition, LA remodeling as a result of disease processes is frequently asymmetrical, rendering the standard geometric assumptions even more inadequate. Not surprisingly, several studies have shown that 2DE underestimates LAV compared with imaging techniques that are free of these limitations, such as cardiac computed tomography (3,4) and cardiac magnetic resonance (CMR) (5). Importantly, this underestimation may contribute to misclassification of patients with LV diastolic dysfunction (6).

**ABBREVIATIONS AND ACRONYMS**

**2DE** = 2-dimensional echocardiography

**3DE** = 3-dimensional echocardiography

**CMR** = cardiac magnetic resonance

**LA** = left atrial

**LAV** = left atrial volume

**LAVi** = left atrial volume index

**LV** = left ventricular

Because real-time 3-dimensional echocardiography (3DE), the natural extension of 2DE, can overcome these limitations by allowing direct detection of LA boundaries in 3-dimensional space, it is attractive as a potentially more accurate and more reproducible alternative for the LAV measurements (7–9). However, few studies have prospectively validated 3DE-derived LAV measurements in large groups of patients against an accepted independent reference standard (10,11) because of the lack of appropriate tools for volumetric analysis of LAV from 3DE datasets, the high cost of CMR or cardiac computed tomography studies, and the radiation concerns associated with the latter. Also, none of the published studies were performed prospectively in a multicenter setting.

Accordingly, this study was designed to: 1) prospectively validate in a multicenter setting new dedicated volumetric software for LAV measurement from 3DE datasets against a CMR reference; 2) compare the accuracy and reproducibility of this analysis with those of 2DE-based LAV measurements; and 3) determine the added value of 3DE over 2DE measurements of LAV for the interpretation of LV diastolic function.

## METHODS

**Study design.** To achieve these goals, we studied patients with a wide range of LAV referred for CMR evaluation at 4 institutions. In each patient, 2DE, 3DE, and CMR imaging were performed on the same day. All images were analyzed to measure LAV at end-ventricular systole (just before mitral valve opening), while excluding the LA appendage. The LAV index (LAVi), defined as LAV normalized by body surface area, was also calculated. The 2DE and 3DE measurements were compared with the CMR reference values. Repeated measurements were performed to assess the reproducibility of LAV measurement by the 3 techniques: 2DE, 3DE, and CMR imaging.

**Study population.** Ninety-two patients (48 ± 18 years of age, 57 men and 35 women, body surface area of 1.72 ± 0.34 ml/m$^2$), referred for clinically indicated CMR for a wide range of suspected cardiovascular conditions, were studied. These 92 patients were selected from 107 consecutive patients, who agreed to participate, on the basis of adequate echocardiographic image quality to allow LAV measurements. CMR-derived maximal LAVs ranged between 40 ml and 206 ml. Exclusion criteria were previous cardiac surgery and known contraindications to CMR, including pacemaker or defibrillator implantation, atrial arrhythmia, claustrophobia, and dyspnea precluding a 10- to 15-s breath-hold. The protocol was approved by the institutional review board of each participating institution. Written informed consent was obtained from each patient.

**Magnetic resonance imaging.** CMR images were obtained using a 1.5-T scanner with a phased-array cardiac coil. Equipment manufacturers varied among institutions and included Philips (Intera Achievea, Best, the Netherlands), Siemens (MAGNETOM Sonata, Erlangen, Germany), and General Electric (Sigma EXCITE, Milwaukee, Wisconsin). In each patient, retrospective electrocardiogram-gated localizing spin-echo sequences were used to identify the long axis of the heart. Steady-state free-precession dynamic gradient echo (balanced TFE for Philips, TrueFISP for Siemens, and FIESTA for General Electric) cine loops of the left atrium (8-mm thick short-axis slices with 2-mm gaps and 2.0 × 2.0-mm in-plane spatial resolution) were then obtained using retro-