Left Atrial Volume: Comparison of 2D and 3D Transthoracic Echocardiography with ECG-gated CT Angiography

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Rationale and Objectives: Left atrial volume (LAV) measurement by conventional two-dimensional (2D) transthoracic echocardiography (TTE) may be limited by the geometric model, by suboptimal definition of left atrial endocardium, or by chamber foreshortening. Three-dimensional (3D) TTE is posited to eliminate chamber foreshortening, and LAV measurement by 3D TTE should be more reflective of true LAV. The aim of this study was to compare conventional 2D TTE and newer 3D TTE for measurements of LAV to multidetector computed tomographic (MDCT) measurements using automated chamber reconstruction (ACR).

Materials and Methods: Twenty-two subjects consented to undergo 2D TTE and 3D TTE immediately prior to or following coronary computed tomographic angiography. LAV was calculated from 2D TTE using the area-length method (ALM) and from 3D TTE with the ALM as well as with a 3D model. Electrocardiographically gated coronary computed tomographic angiography was performed in helical mode. LAV was measured using the ALM as well as ACR.

Results: LAV was significantly smaller by 2D TTE (80 $\pm$ 21 mL) and 3D-TTE (90 $\pm$ 24 mL with the ALM, 61 $\pm$ 16 mL with the 3D model) compared to MDCT ACR (120 $\pm$ 30 mL) ($P < .01$). Correlation between MDCT ALM and MDCT ACR was excellent (mean $\Delta = -1.4 \pm 14$ mL, $r = 0.91$). Correlation with MDCT ACR was no better for 3D TTE ($r = 0.80$) than for 2D TTE ($r = 0.80$).

Conclusions: LAV is underestimated by both 2D TTE and 3D TTE relative to coronary computed tomographic angiography. Excellent agreement between the ALM and ACR with MDCT imaging suggests that the geometric model plays a negligible role in the underestimation of LAV. Underestimation of LAV by echocardiography is likely related to suboptimal definition of left atrial contour.

Key Words: Left atrium; left atrial volume; echocardiography; CT angiography; area-length method; automatic chamber reconstruction.

Left atrial size is an important marker for a variety of clinical disease states. Elevated left atrial size predicts diastolic dysfunction (1), the severity of mitral regurgitation (2), and the likelihood of success of pulmonary vein isolation in treating atrial fibrillation (3). Increased left atrial size portends poorer outcomes in patients with atrial fibrillation (4–6), myocardial infarction (7,8), and dilated cardiomyopathy (9). Thus, accurate measurement of left atrial size is of primary importance.

Historically, computed tomographic (CT) imaging and magnetic resonance imaging (MRI) have served as gold standards for left atrial volume (LAV), and two-dimensional (2D) transthoracic echocardiography (TTE) was validated against these reference standards (10,11). Echocardiography is currently the most common modality used to measure the left atrium because of its lower cost, portability, and universal availability. The current recommended standard to estimate LAV as defined by the American Society of Echocardiography uses an ellipsoid geometric model derived from two orthogonal apical views with the biplane area-length method (ALM) (12). Unfortunately, because the ALM depends on the acquisition of two nonforeshortened images, and on a geometric estimate, it is prone to errors.

Theoretically, three-dimensional (3D) TTE should provide the most accurate evaluation of LAVs, because it is not prone to errors related to chamber foreshortening or geometric estimation. Until recently, however, 3D TTE has had limited clinical applicability because of relatively laborious and time-intensive acquisition and offline processing (13,14). The introduction of "real time" 3D TTE using matrix-array transducers has resulted in sufficiently rapid image acquisition for clinical applications, but has not been rigorously validated (15). Recently automated edge reconstruction algorithms on multidetector CT (MDCT) imaging provide the ability to rapidly assess chamber volumes precisely and accurately (16,17). The aim of this study was to use 3D transthoracic echocardiographic software to measure

Acad Radiol 2012; 19:62–68

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doi:10.1016/j.acra.2011.08.017

LAV and compare this to a CT reference standard to assess the accuracy of current-generation 3D TTE.

METHODS

Patient Selection

From November 2009 to July 2010, consecutive subjects who were referred for cardiac MDCT imaging during daytime hours (9 AM to 4 PM), when a research sonographer was available, were asked to participate in the study. MDCT studies and echocardiographic studies on any individual patient were performed consecutively with a minimum possible delay between the studies. There were no exclusion criteria. This study was compliant with the Health Insurance Portability and Accountability Act and was approved by our local institutional review board. All study subjects were aged ≥18 years and provided written informed consent prior to inclusion in the study.

Echocardiography

Patients were positioned in the left lateral decubitus position. Echocardiography was performed either immediately before or after cardiac MDCT imaging. All measurements were performed offline using Xcelera, QLAB, and 3DQ-Advanced software (Phillips Medical Systems, Andover, MA). Two-dimensional images were acquired using the S5-1 probe on a Phillips iE33 machine (Phillips Medical Systems). Standard apical four-chamber and two-chamber views were obtained (Fig 1). LAV was calculated using the biplane ALM as recommended by American Society of Echocardiography guidelines (12). The formula applied was $A1 \times A2 \times 0.85/L$, where $A1$ is the area in the apical four-chamber view, $A2$ is the area in the apical two-chamber view, and L is the shorter length of the left atrium. These measurements were performed by two independent observers (A.R.K. and A.N.O.) who were blinded to the MDCT results.

Apical real-time 3D images were acquired using the X3-1 matrix ultrasound probe on a Phillips iE33 machine (Fig 2). Apical full-volume images were acquired over four to seven cycles. The image was aligned to obtain the best endocardial border definition prior to acquisition. LAV was measured at end-systole as defined by the frame before opening of the mitral valve. The 3D longitudinal axes were aligned through the center of the left atrium to avoid foreshortening. Semiautomated border tracking was then performed by selecting four points around the mitral annulus (septal, lateral, anterior, and inferior) and one point at the perceived apex or superior border of the left atrium. LA systolic volume was automatically calculated by the software using an edge detection algorithm. Endocardial borders were then checked and manually edited by two independent observers (A.R.K. and A.N.O.), who were blinded to the MDCT results.

To determine whether areas on 2D TTE may be underestimated because of chamber foreshortening, we repeated the ALM measurements on the basis of areas obtained from nonforeshortened four-chamber and two-chamber images from 3D TTE.

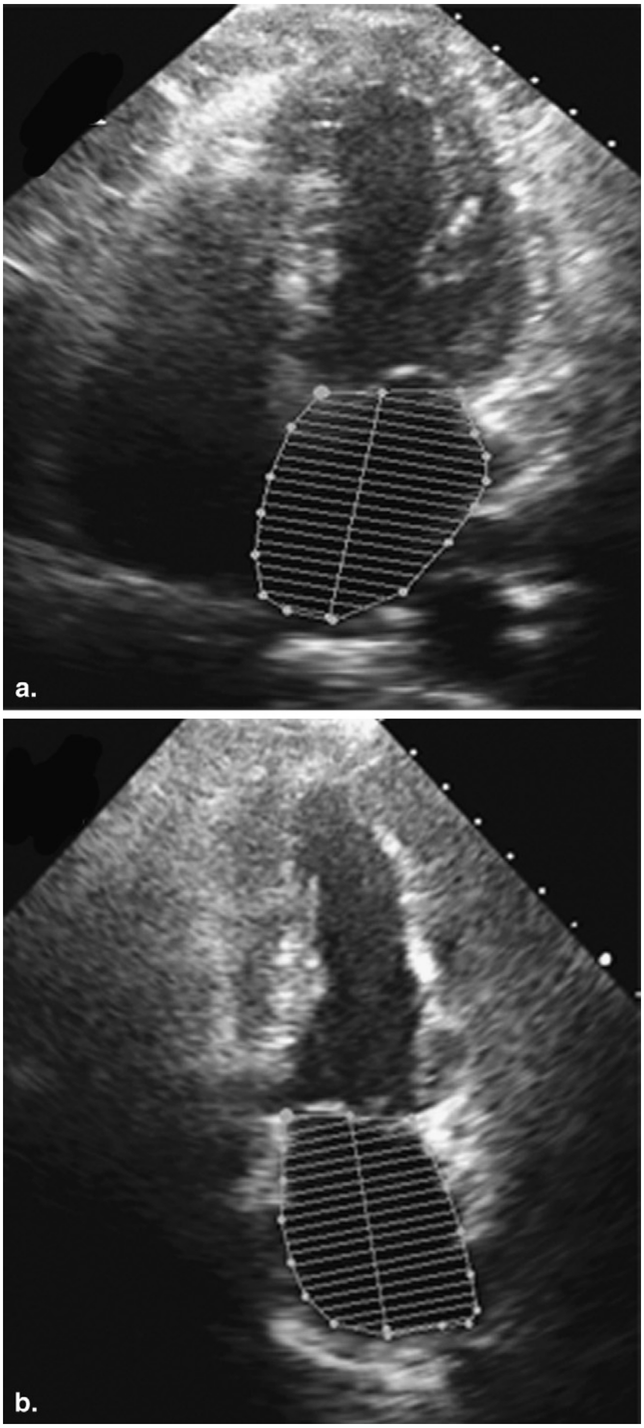

Figure 1. Standard transthoracic echocardiographic views with measurements of left atrial area used for calculation of left atrial volume. **(a)** Apical four-chamber view. **(b)** Apical two-chamber view.

Cardiac MDCT Imaging

All MDCT examinations were performed using a helical acquisition on a 256-slice iCT scanner (Philips Medical Systems,