Head-to-Head Comparison of Two-Dimensional and Three-Dimensional Echocardiographic Methods for Left Atrial Chamber Quantification with Magnetic Resonance Imaging

Ronny R. Buechel, MD, Frank Peter Stephan, MD, Gregor Sommer, MD, Jens Bremerich, MD, Michael J. Zellweger, MD, and Beat A. Kaufmann, MD, *Basel, Switzerland*

Background: Limited data are available on the accuracy of quantification methods for left atrial (LA) volumes using two-dimensional (2D) and particularly real-time three-dimensional echocardiographic (RT3DE) methods in comparison with a reference standard. The aim of this study was to perform a head-to-head comparison between 2D and RT3DE methods with magnetic resonance imaging (MRI) as the reference standard.

Methods: LA volumes derived from 2D echocardiographic methods (i.e., biplane modified Simpson's, biplane area-length, and prolate ellipse methods) and from RT3DE methods (i.e., 4D LA Analysis and QLAB) in 60 consecutive patients were compared with MRI measurements. Offline analysis time was recorded.

Results: The biplane modified Simpson's and area-length methods showed good intraclass correlations with MRI for maximum ($r = 0.70$ and $r = 0.69$, $P < .001$) and minimum ($r = 0.83$ and $r = 0.82$, $P < .001$) volumes. Although RT3DE methods led to moderate increases in correlations for maximum ($r = 0.94$ and 0.70, $P < .001$) and minimum ($r = 0.95$ and $r = 0.90$, $P < .001$) volumes and narrower Bland-Altman limits of agreement than 2D echocardiographic methods, offline analysis time was higher for RT3DE (155-161 vs 103-144 sec). Compared with MRI, maximum and minimum LA volumes were underestimated by −4.7% and −8.9%, respectively, using 4D LA Analysis, by −15.7% and −14.9% using QLAB, by −12.3% and −4.4% using the biplane Simpson's method, by −13.7% and −6.8% using the area-length method, and by −48.2% and −50.5% using the prolate ellipse method.

Conclusions: The biplane Simpson's and area-length methods offer reasonable accuracy for LA chamber quantification across a broad range of volumes, while RT3DE methods lead to a moderate improvement in accuracy at the cost of more elaborate offline analysis. (J Am Soc Echocardiogr 2013;26:428-35.)

Keywords: Echocardiography, Real-time three-dimensional echocardiography, Left atrial volume, Comparison

As a consequence of the ongoing technical advances in echocardiography, novel methods for the measurement of left atrial (LA) volumes have been developed. Although M-mode measurement of LA anterior-posterior diameter represents a simple unidimensional assessment of LA size, the introduction of two-dimensional (2D) echocardiography (2DE) has led to volume-based methods. The latter, namely the biplane area-length method (AL) and the biplane modified Simpson's rule, are recommended in guidelines for measuring LA volumes because of their higher accuracy and stronger prognostic value.[1,2] 2DE methods, however, rely heavily on mathematical formulas based on geometric assumptions. The advent of real-time three-dimensional echocardiographic (RT3DE) imaging has enabled volumetric and functional quantification on the basis of real anatomic configurations. Initially, RT3DE LA analysis was performed using freehand[3] or semiautomated slice-by-slice contouring[4,5] and later using software analysis tools using semiautomated contour-tracing or edge detection algorithms originally developed for left ventricular quantification.[6,7] Software tools dedicated specifically to LA quantification have only recently been introduced.[8]

The accuracy of LA assessment may be of clinical importance, as it has repeatedly been suggested that size and function serve as independent predictors of adverse outcomes in a variety of clinical conditions, such as myocardial infarction, atrial fibrillation, and heart

From the Department of Cardiology (R.R.B., F.P.S., M.J.Z., B.A.K.) and the Department of Radiology (G.S., J.B.), University Hospital Basel, Basel, Switzerland.

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Reprint requests: Ronny R. Buechel, MD, University Hospital Basel, Department of Cardiology, Petersgraben 4, CH-4031 Basel, Switzerland (E-mail: *buechelr@uhbs.ch*).

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Abbreviations

AL = Biplane area-length method

CI = Confidence interval

LA = Left atrial

LA_{max} = Maximum left atrial volume at end-systole

LA_{min} = Minimum left atrial volume at end-diastole

MRI = Magnetic resonance imaging

PE = Prolate ellipse method

RT3DE = Real-time three-dimensional echocardiography

2D = Two-dimensional

2DE = Two-dimensional echocardiography

failure.[9-15] Although some of the available techniques for LA chamber quantification have been compared with each other[4,5,16-18] and to some extent have been validated against independent reference standards such as magnetic resonance imaging (MRI) or computed tomography,[6-8,19-22] there remains a lack of comprehensive data comparing 2DE quantification methods and the more recently established RT3DE techniques against an independent reference standard. Particularly, the gain in accuracy through the use of presumably more elaborate RT3DE techniques remains to be elucidated.

Therefore, the aim of the present study was to perform a comprehensive head-to-head comparison of commonly available techniques for LA chamber quantification using 2DE and RT3DE imaging, with cardiac MRI serving as the reference standard.[20,22]

METHODS

Patient Population

Sixty consecutive patients scheduled for pulmonary vein isolation because of symptomatic persistent or paroxysmal atrial fibrillation who underwent clinically indicated cardiac MRI were prospectively enrolled in the present study. Echocardiography was performed in all patients on the same day as MRI, and patients were enrolled regardless of the quality of the acoustic window obtained during acquisition. Informed consent was obtained from all patients, and the study protocol was approved by the local institutional review board.

Echocardiographic Image Acquisition and Quantification

Image acquisition was performed in all participants in the lateral recumbent position using a commercially available echocardiography system (iE33; Philips Medical Systems, Andover, MA) equipped with a 2.5-MHz to 3.5-MHz matrix-array transducer (X3-1 and X5-1; Philips Medical Systems) by a trained sonographer following a standardized protocol. Parasternal long-axis and apical long-axis views were acquired for 2D imaging. For RT3DE imaging, an apical view enabling full coverage of the left atrium was selected, and lateral sector size was carefully adjusted to achieve the highest possible frame rate during image acquisition. Trigger delay was set to 300 msec after the electrocardiographic QRS complex to ensure temporal coverage of the entire diastole using a full-volume loop. Two to four data sets were obtained per patient, and gain settings were adjusted to a high midrange level to allow additional adjustments during postprocessing. All data sets were acquired during breath-hold.

All data sets were transferred to a dedicated workstation for offline analysis. Measurements of three-dimensional LA volumes were performed using two different three-dimensional quantification software packages: QLAB Advanced Quantification version 8.1 (Philips Medical Systems) and 4D LA Analysis (TomTec Imaging Systems, Munich, Germany). QLAB was initially developed for left ventricular analysis and requires the identification of five anatomic landmarks (the septal, lateral, anterior, and inferior mitral annulus and the posterior wall of the left atrium) at end-diastole and end-systole. Automatic edge detection is then performed, and LA borders are tracked throughout the entire cardiac cycle (Figure 1). In contrast, 4D LA Analysis is a novel software analysis tool developed specifically for RT3DE analysis of the left atrium. Using this analysis tool, the reader first identifies mitral valve closure and mitral valve opening to manually define the end-diastolic frame representing minimum LA volume (LA_{min}) and the end-systolic frame representing maximum LA volume (LA_{max}). In a further step, the initial contours of the left atrium at end-diastole and end-systole are manually defined for the apical four-chamber, two-chamber, and long-axis views (Figure 2). A polyhedral model of the left atrium is then automatically created by the software tool using an automated border detection technique. In the following step, the contours are manually corrected, if necessary. The pulmonary vein orifices and/or LA appendage were not included in the contour. For both methods, LA_{max} and LA_{min} were calculated.

For 2DE LA volume quantification, three commonly used methods were applied. AL uses the formula $V = 8(A_1)\ (A_2)/3\pi\ (L)$, where A_1 and A_2 represent areas obtained from LA planimetry in four-chamber and two-chamber views, and L is the shortest length from the center of the mitral annular plane to the superior aspect of the left atrium (Figures 3A and 3B). The biplane modified Simpson's rule, assuming the stacked disks are circular, uses the formula $V = \pi/4\ (L) \sum(A_1)\ (A_2)$, where V is volume, L is the length from the center of the mitral annular plane to the superior aspect of the left atrium, and A_1 and A_2 represent the 20 disks obtained from the four-chamber and two-chamber views (Figures 3A and 3B). The prolate ellipse method (PE) uses the formula $V = 0.523\ (D_1)\ (D_2)\ (D_3)$, where D_1 is measured from the middle of the plane of the mitral annulus to the superior aspect of the left atrium in a four-chamber view, D_2 is the orthogonal short-dimension to D_1, and D_3 reflects the anterior-posterior diameter measured in a parasternal long-axis (Figures 3C and 3D). All 2DE measurements were performed at end-diastole and end-systole to obtain LA_{max} and LA_{min}. As with RT3DE imaging, end-diastole and end-systole were identified using mitral valve closure and mitral valve opening as reference points to ensure identical timing.

Analysis time in seconds was recorded for all echocardiographic methods from the time the data sets were loaded into the respective software tool until LA_{max} and LA_{min} were calculated.

Intraobserver and interobserver agreement was assessed using repeated measurements from 15 randomly selected subjects ≥2 months after the first analysis. The second observer used the same data sets for offline analysis as the first observer but was blinded to the results or identities of the subjects. A dedicated workstation was used for analysis by the second observer to ensure blinding.

Magnetic Resonance Image Acquisition and Quantification

A 1.5-T clinical system (Magnetom Espree; Siemens Healthcare, Erlangen Germany) with multichannel phased-array receiver coils (Total imaging matrix; Siemens Healthcare) was used to perform MRI acquisition, with patients in the supine position. Localizing scans were followed by a series of transversely oriented cine acquisitions using a balanced steady-state free precession sequence (repetition