Feasibility and Accuracy of Automated Software for Transthoracic Three-Dimensional Left Ventricular Volume and Function Analysis: Comparisons with Two-Dimensional Echocardiography, Three-Dimensional Transthoracic Manual Method, and Cardiac Magnetic Resonance Imaging

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Background: Recently, a new automated software package (HeartModel) was developed to obtain three-dimensional (3D) left ventricular (LV) volumes using a model-based algorithm (MBA) with a "one-button" simple system and user-adjustable slider. The aims of this study were to verify the feasibility and accuracy of the MBA in comparison with other commonly used imaging techniques in a large unselected population, to evaluate possible accuracy improvements of free operator border adjustments or changes of the slider's default position, and to identify differences in method accuracy related to specific pathologies.

Methods: This prospective study included consecutive 200 patients. LV volumes and ejection fraction were obtained using the MBA and compared with the two-dimensional biplane method, the 3D full-volume (3DFV) modality, and, in 90 of 200 cases, cardiac magnetic resonance (CMR) measurements. To evaluate the optimal position of the slider with respect to the 3DFV and CMR modalities, a set of threefold cross-validation experiments was performed. Optimized and manually corrected LV volumes obtained using the MBA were also tested. Linear correlation and Bland-Altman analysis were used to assess intertechnique agreement.

Results: Automatic volumes were feasible in 194 patients (94.5%), with a mean processing time of 29 ± 10 sec. MBA-derived volumes correlated significantly with all evaluated methods, with slight overestimation of two-dimensional biplane and slight underestimation of CMR measurements. Higher correlations were found between MBA and 3DFV measurements, with negligible differences both in volumes (overestimation) and in LV ejection fraction (underestimation), respectively. Optimization of the user-adjustable slider position improved the correlation and markedly reduced the bias between the MBA and 3DFV or CMR. The accuracy of MBA volumes was lower in some pathologies for incorrect definition of LV endocardium.

Conclusions: The MBA is highly feasible, reproducible, and rapid, and it correlates highly with the traditional 3DFV method. It may represent a valid alternative to 3DFV measurement for everyday clinical use. (J Am Soc Echocardiogr 2017;■:■-■.)

Keywords: Three-dimensional echocardiography, Left ventricle, Left ventricular function

An accurate and reproducible assessment of left ventricular (LV) volumes and function is very important in all cardiac diseases and is the most frequent indication for an echocardiographic study in daily practice.[1-3] The geometric assumptions necessary to obtain LV volumetric reconstruction and the suboptimal inter- and intraobserver variability in two-dimensional (2D) echocardiography are known to limit this technique.[4,5] The introduction of three-dimensional (3D) echocardiography with LV dedicated software has allowed a more reliable analysis of LV volumetric and functional data, thus increasing reproducibility in comparison with 2D echocardiography and accuracy in comparison with cardiac magnetic resonance (CMR).[6-11]

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Abbreviations

2D = Two-dimensional

2DBP = Two-dimensional biplane

3D = Three-dimensional

3DFV = Three-dimensional full-volume

CMR = Cardiac magnetic resonance

ICC = Intraclass correlation coefficient

LV = Left ventricular

LVEDV = Left ventricular end-diastolic volume

LVEF = Left ventricular ejection fraction

LVESV = Left ventricular end-systolic volume

MBA = Model-based algorithm

However, especially at the beginning, cumbersome acquisition methods and complicated and time-consuming analysis software reduced the diffusion of 3D echocardiography in routine LV evaluation.[12-14] Improvements in "on-board" semiautomatic volumetric methods have allowed increasing use of LV 3D echocardiographic quantification, even though, for everyday clinical use, 3D echocardiographic LV volumetric evaluation will be ready only with the introduction of more simple and fast acquisition modalities and automatic chamber quantification techniques.[15-18]

Recently, a new automated software package has been developed to obtain LV volumes from real-time 3D echocardiographic acquisitions using a model-based adaptive analytic algorithm with a "one-button" simple system and a user-adjustable slider for the detection of endocardial borders. This new method was recently evaluated, demonstrating that simultaneous quantification of left atrial and LV volumes and LV ejection fraction (LVEF) is feasible and requires minimal 3D software analysis training.[19-21]

The aim of this study was threefold: (1) to verify the feasibility and accuracy of the model-based algorithm (MBA) in comparison with the 2D biplane (2DBP) method, 3D full-volume (3DFV) modality (3DFV), and CMR in a large population of patients; (2) to evaluate if changes in MBA volumetric reconstruction through operator border adjustments or repositioning of the slider border definition might improve the MBA's accuracy; and (3) to identify differences in method accuracy relating to specific pathologies.

METHODS

We prospectively recruited 200 consecutive patients in sinus rhythm referred to the echocardiography laboratory of Centro Cardiologico Monzino of Milan for measurement of LV volumes and LVEF. After the exclusion of six patients with technically inadequate echocardiographic images, a study group of 194 patients remained who underwent 2D and 3D echocardiography.

For clinical reasons, CMR studies were performed in 90 of these 194 patients. The population consisted of 34 normal subjects and 160 patients with valve disease ($n=68$), coronary artery disease ($n=23$), dilated cardiomyopathy ($n = 53$), and congenital or hypertrophic disease ($n = 16$). The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the institution's human research committee and was approved by the institutional review board. Informed consent was obtained from each patient.

Two-Dimensional Echocardiography

All echocardiographic examinations were performed using a Philips echocardiographic system (EPIQ, iE33, X5 transducer; Philips Healthcare, Andover, MA). A complete standard 2D echocardiographic examination was performed. Biplane LV end-diastolic volume (LVEDV), LV end-systolic volume (LVESV), and LVEF were measured from the four- and two-chamber views using Simpson's method.[10]

Three-Dimensional Echocardiography

With the same echocardiographic system and same transducer, at the end of the two-dimensional echocardiographic study, 3D echocardiographic acquisitions were obtained from the four-chamber apical view in full-volume mode (3DFV), gathered over four cardiac cycles, during a breath-hold lasting a few seconds.[11]

Three-Dimensional Full-Volume

For the semiautomatically derived 3D echocardiographic method, LV volumetric data sets were measured using commercially available software (QLAB-3DQ Adv; Philips Healthcare). Briefly, the operator aligns the multiplanar view to optimize horizontal and vertical lines in the middle of the LV cavity. Then five reference points are placed (septal, lateral, anterior, and inferior mitral annulus and apex) at the end-diastolic and end-systolic frames. Both the end-diastolic and end-systolic frames are automatically obtained by the software, but if necessary, the correct frame may be modified by the operator. Finally, the software automatically identifies the LV endocardial border and creates a 3D LV model providing LV volumes and calculating LVEF. A suboptimal automatic endocardial border delineation may be manually adjusted when necessary.

Model-Based Algorithm

This new 3D echocardiographic software involves an automated analysis that simultaneously detects LV and left atrial endocardial surfaces using an adaptive analytics algorithm. The program and methodology of the system have been previously described.[18] In brief, in each patient two or more acquisitions were performed using the new automatic method from the same four-chamber apical window during a brief breath-hold period. When LV acquisition was obtained, touching the icon of the MBA software on the echocardiography screen, LV volumes, stroke, and LVEF were calculated without operator intervention (Figure 1). MBA software automatically detects the LV wall inner border at the blood-tissue interface and outer border located at compacted myocardium interface. In the default setting, a slider is positioned in the middle between the two borders (default setting = 50), and in this position LV volume is automatically assembled. However, this user=adjustable slider may be freely moved from the default position to arbitrarily optimize LV border identification, and different slider positions can be preset to a user's preference. The default slider position was used as the MBA reference value both for end-diastolic and end-systolic volumes. Figure 1 shows an example of MBA imaging.

Different User-Adjustable Slider Positions and Free Adjustment of the Automatic Border

To improve the correlations between MBA and CMR or 3DFV, two correction modalities of automatic MBA reconstruction were used: fixed changes of the default slider position and free adjustment of the automatic border.

For fixed changes of default slider position, the operator moves the user-adjustable sliders toward the optimal blood-tissue interface or outer border at compacted myocardium interface to optimize the endocardial recognition (MBA optimized). For free adjustment of