Three-Dimensional Echocardiographic Automated Quantification of Left Heart Chamber Volumes Using an Adaptive Analytics Algorithm: Feasibility and Impact of Image Quality in Nonselected Patients

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Background: Although 3D echocardiography (3DE) allows accurate and reproducible quantification of cardiac chambers, it has not been integrated into clinical practice because it relies on manual input, which interferes with workflow. A recently developed automated adaptive analytics algorithm for simultaneous quantification of left ventricular and atrial (LV, LA) volumes was found to be accurate and reproducible in patients with good images. We sought to prospectively test its feasibility and accuracy in consecutive patients in relationship with image quality and reader experience.

Methods: Three hundred consecutive patients underwent 3DE. Image quality was graded as poor, adequate, or good. Images were analyzed by an expert echocardiographer to obtain LV volumes and ejection fraction (EF) and LA volume using the automated analysis (HeartModel, Philips, Andover, MA) with and without editing the endocardial boundaries and using conventional manual tracing (QLAB, Philips, Andover, MA) blinded to the automated measurements as a reference. In a subgroup of 100 patients, automated analysis was repeated by two readers without 3DE experience.

Results: Automated analysis failed in 31/300 patients (10%). Patients with poor image quality (n = 72, 24%) showed suboptimal agreement with the reference technique, especially for LVEF. Importantly, patients with adequate (n = 89, 30%) and good (n = 108, 36%) images showed small biases and excellent correlations without border corrections, which were further improved with editing. In contrast, border corrections by inexperienced readers did not improve the agreement with reference values.

Conclusions: Automated 3DE analysis allows accurate quantification of left-heart size and function in 66% of consecutive patients, while in the remaining patients, its performance is limited/unreliable due to image quality. Border corrections require 3DE experience to improve the accuracy of the automated measurements. In patients with sufficient image quality, this automated approach has the potential to overcome the workflow limitations of the 3D analysis in clinical practice. (J Am Soc Echocardiogr 2017;■:■-■.)

Keywords: 3D echocardiography, Cardiac chamber quantification, Automation

Three-dimensional (3D) echocardiography (3DE) has been shown to have advantages over two-dimensional (2D) imaging in multiple areas and thus has been gradually incorporated into clinical routine in many echocardiography laboratories throughout the world. Improved accuracy and reproducibility of the quantification of cardiac chamber size and function is one of the major advantages of 3DE over 2D echocardiography (2DE). This is because the volumetric 3DE approach, which directly counts pixels inside the endocardial surface, does not rely on geometrical assumptions and thus avoids the risk of underestimating chamber volumes due to the use of foreshortened views,[1-3] which are common with 2DE. The equipment and analysis software of 3DE is now widely available, and the rising numbers of publications have placed this technology as an evolving new standard for chamber quantification. The higher accuracy and reproducibility translate into improved clinical prognostic significance, which is the reason why 3DE is the recommended technique by the recently published guidelines for quantification of left-heart chambers.[4] Nevertheless, currently available analysis techniques rely on extensive user input,

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Abbreviations

2D = Two-dimensional

2DE = Two-dimensional echocardiography

3D = Three-dimensional

3DE = Three-dimensional echocardiography

ED = End-diastolic

EDV = End-diastolic volume

EF = Ejection fraction

ES = End-systolic

ESV = End-systolic volume

HM = HeartModel

LA = Left atrial

LAV = Left atrial volume

LV = Left ventricular

which requires expertise and adversely affects the workflow and thus impedes the implementation in busy clinical laboratories.[1,5,6] As a result, most clinical laboratories still use traditional, frequently qualitative, 2DE assessment of cardiac function.

To overcome these limitations, we recently tested a new automated approach for left-heart chamber quantification based on an adaptive analytics algorithm. In a single-center study, we reported good accuracy and reproducibility, and improved speed of analysis, compared with the conventional 3DE methodology and cardiac magnetic resonance.[7] In a more recent multicenter study, we showed that it is an accurate and robust alternative to conventional manual methodology, which yields almost the same values across laboratories and is more reproducible.[8] However, these studies included only patients with good-quality images.

Furthermore, current 3DE acquisition is based on combining multiple beats (usually 4 to 6) to generate a single full-volume data set, which is needed to obtain a high enough frame rate for accurate analysis of cardiac function. This multibeat acquisition is associated with "stich artifacts," which are particularly common in patients with arrhythmias and those who cannot hold their breath, precluding accurate analysis. To circumvent this limitation, the new automated analysis utilizes a different, high frame rate, single-beat 3D acquisition mode. However, the impact of this new acquisition mode on the accuracy of chamber size and function measurements is unknown.

Accordingly, the main goal of this study was to assess the feasibility of this automated technique in consecutive nonselected patients and evaluate the effects of image quality on its accuracy. The additional goals were to evaluate the effects of reader experience with 3DE and the high frame rate, single-beat acquisition mode on the accuracy of the automated analysis.

METHODS

Population and Study Design

We prospectively studied 300 consecutive nonselected patients (age, 63 ± 17; female, 54%; body surface area, 1.9 ± 0.2 m^2) referred for clinically indicated transthoracic echocardiograms for a wide range of suspected cardiovascular conditions (Table 1) who underwent in addition 3DE imaging. Noncooperative patients or those who refused to participate were excluded; no other exclusion criteria were applied. The protocol was approved by the Institutional Review Board, and informed consent was obtained from each patient.

Images were analyzed by an experienced echocardiographer, who used the automated 3DE software to measure left heart chamber size and function indices, with and without endocardial boundary corrections. To generate a reference standard, the same reader used the conventional approach based on 3D-guided biplane measurements, while blinded to the results of the automated analysis. These comparisons were used to determine the accuracy of the automated analysis when images were classified by quality. In addition, to evaluate the effects of reader experience on the ability to effectively edit endocardial borders and thus potentially improve the accuracy of the automated analysis, measurements were repeated in a subset of randomly selected 100 patients by two readers without 3DE experience (third-year general cardiology fellows) and compared against the same reference standard.

To assess the effects of the high frame rate, single-beat acquisition on the accuracy of the 3DE measurements, 30 patients with good-quality images were imaged in addition using the conventional 4-beat full-volume mode. These 4-beat data sets were analyzed using conventional semiautomated volumetric analysis and used as the reference for comparisons.

Echocardiographic Imaging

Imaging was performed using the EPIQ system (version 7C, Philips Medical Systems, Andover, MA) and an X5-1 phased-array transducer with the patient in the left lateral decubitus position. Before each acquisition, images were optimized for endocardial visualization by modifying the gain, compress, and time-gain compensation controls. Image acquisition included wide-angled, single-beat, high frame rate 3DE data sets (HM ACQ key on the EPIQ system) from the apical position during a single breath hold. Care was taken to include the entire left ventricular (LV) and left atrial (LA) cavity within the 3DE images. Imaging depth and sector width were optimized to obtain the highest possible frame rate. In addition, in a subset of 30 patients, a conventional 4-beat full-volume acquisition was performed in the same setting using the same equipment.

Three-Dimensional Echocardiography Image Analysis

Images were reviewed and analyzed by an expert echocardiographer with extensive training in 3DE. First, the image quality of the 3DE images was graded by reviewing two-, three-, and four-chamber views extracted from the 3D data set as poor (more than two of six contiguous segments not visualized in any view or two of six contiguous segments in at least two different views), adequate (not more than two of six not well visualized contiguous segments in one view and one or fewer in the other views), and good (better than adequate).

Then the automated analysis was performed (HeartModel [HM], Philips) to obtain LV end-diastolic (ED) and end-systolic (ES) volumes (EDV, ESV) and LA volume (LAV) measurements, and LV ejection fraction (EF) was calculated. Analysis methodology was described in detail in our recent publications.[7,8] Briefly, the software simultaneously detects LV and LA endocardial surfaces using an adaptive analytics algorithm, which uses knowledge-based identification to orient and locate cardiac chambers and patient-specific adaptation of endocardial borders. The algorithm automatically identifies the ED and ES phases of the cardiac cycle, and creates ED and ES 3D casts of the LV cavity and an ES cast of the LA cavity, from which LV and LA volumes are derived directly without geometrical assumptions. Manual corrections of the LV and LA endocardial surfaces are possible, when the operator judges the automatically detected surface as suboptimal. This is achieved by displaying the LA and LV contours on four-, three-, and two-chamber cut planes extracted from the 3DE data sets and allowing the user to edit the contours to optimize the match between the detected and the perceived endocardial boundaries (Figure 1).