Assessment of Left Ventricular Volumes with Echocardiography and Cardiac Magnetic Resonance Imaging: Real-Life Evaluation of Standard versus New Semiautomatic Methods

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Background: Routine quantitative assessment of left ventricular (LV) volumes with echocardiography is hindered by time-consuming methods requiring a manual trace of the LV cavity from two apical two-dimensional planes. Thus, the aim of this study was to evaluate faster new semiautomatic echocardiographic methods that could represent a feasible alternative for the assessment of LV volumes and ejection fraction (EF) in clinical practice.

Methods: Two semiautomatic methods, the automated EF (Auto-EF) for two-dimensional echocardiography and the 4D Auto LVQ tool for three-dimensional echocardiography (3DE), were compared with the biplane modified Simpson's method and cardiac magnetic resonance (CMR) imaging in 47 patients. To evaluate the accuracy of volumetry, additional in vitro measurements using water-filled latex balloons were performed with both modalities.

Results: Results of balloon volumetry by echocardiography and CMR measurements were in good agreement with real balloon volumes. The mean LV EF was 45 ± 11% by Auto-EF, 45 ± 11% by 3DE, 48 ± 11% by Simpson's method, and 54 ± 12% by CMR. Linear regression and Bland-Altman analyses showed good associations for semiautomatic methods with Simpson's method (Auto-EF, $r = 0.85$, bias = 3%, limits of agreement [LOA] = 12%; 3DE, $r = 0.79$, bias = 3%, LOA = 14%), as well as with CMR (Auto-EF, $r = 0.74$, bias = 9%, LOA = 17%; 3DE, $r = 0.73$, bias = 9%, LOA = 17%). Intra- and interobserver variability were 6% and 12% with Auto-EF and 8% and 11% with 3DE, respectively.

Conclusions: Good correlations between semiautomatic echocardiographic parameters for assessment of LV volumes and EF could be observed when compared with Simpson's method or CMR. However, intertechnique agreement analysis of absolute LV volumes revealed considerable differences, with significant underestimation of volumes and EF with respect to CMR. (J Am Soc Echocardiogr 2014;27:1017-24.)

Keywords: Volumetry, Ejection fraction, Systolic function

Many diagnostic and treatment decisions in cardiovascular care include left ventricular (LV) function as a critical component. The indication for the implantation of an internal cardioverter-defibrillator serves as a good example.[1]

Among the different tools for LV function analysis, transthoracic echocardiography is most widely applied. Current guidelines recommend the use of the biplane method of disks (modified Simpson's method) for the determination of LV volumes and calculation of ejection fraction (EF).[2] However, manual tracing of the end-diastolic and end-systolic LV cavity can be time consuming and challenging. New semiautomatic methods based on backscatter recognition of endocardial borders have been developed to overcome these limitations, namely, the automated EF (Auto-EF) for two-dimensional (2D) echocardiography and the 4D Auto LVQ tool, an algorithm for three-dimensional echocardiography (3DE). Although the feasibility of these new methods has been established in previous studies,[3,4] their relative performance in clinical routine settings remains to be determined.

Therefore, we conducted a prospective study comprising two parts. The aim of the first, experimental part was to validate the accuracy of volume assessment with echocardiography and cardiac magnetic resonance (CMR) by use of water-filled latex balloons as an in vitro model. In the second, clinical part, we aimed to evaluate the performance of Auto-EF and the 4D Auto LVQ tool for the assessment of LV volumes and function during routine clinical practice and to compare the agreement of the two semiautomatic methods with

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Abbreviations

Auto-EF = Automated ejection fraction

CMR = Cardiac magnetic resonance

EDV = End-diastolic volume

EF = Ejection fraction

ESV = End-systolic volume

LOA = Limits of agreement

LV = Left ventricular

3DE = Three-dimensional echocardiography

2D = Two-dimensional

the modified biplane Simpson's method as well as with CMR. Care was taken to follow the specific guideline recommendations for LV volume quantification with either echocardiography or CMR.[2,5]

METHODS

In Vitro Volume Validation

Ten water-filled latex balloons of different size and shapes were used to validate the accuracy of Simpson's method for 2D echocardiography (Figure 1A), 4D Auto LVQ for 3DE (Figure 1B), and the Extended MR Workspace software for CMR (Figure 1C). To determine the balloon's volume with Simpson's method and 3DE, we used the visible inner layer of the latex membrane as the boundary. On CMR images, the real inner layer was not detectable, so the outermost margin of the balloon was used as the boundary. Apparently internal balloon borders seen on CMR images depict an artifact known as Gibbs ringing, which represents a mathematical limitation of the Fourier transform.[6]

Balloon volumes were assessed on the same day with all methods and then compared with their real volumes. Water-filled balloon volumes were determined by measuring their weights on a laboratory precision balance and subtracting the weights of the empty balloons, assuming that under standard conditions 1 mL equals 1 g pure water weight. The Auto-EF tool could not be tested as described because it needs a small dynamic volume change of ≥10% to work at all.

Study Population

All patients undergoing clinically indicated CMR examinations in our cardiology department within a time span of 1 month were invited to participate in this study ($n = 183$). Forty-seven patients agreed to undergo additional comprehensive echocardiographic examinations. Clinical characteristics are shown in Table 1. The patient population was heterogeneous: 15 patients had normal myocardial function without critical coronary artery disease; furthermore, 14 patients with cardiomyopathy (10 dilated, two hypertrophic, two cardiac amyloidosis), 10 patients with coronary artery disease (two with one-vessel, two with two-vessel, and six with three-vessel disease), four patients with different forms of known cardiac arrhythmia and/or conduction disorder (Wolff-Parkinson-White syndrome, premature atrial contractions, paroxysmal atrial fibrillation, premature ventricular beats), two patients after heart transplantation, one patient with an atrial septal defect, and one patient with systemic vasculitis were included. All patients were in sinus rhythm during both examinations. To minimize time-dependent variation of hemodynamic characteristics, echocardiography was commenced <30 min after CMR.

Standard as well as two new methods for the assessment of LV volumes and function were conducted in the same cohort. Patients with suboptimal echocardiographic image quality were not excluded, to reflect a real-life patient population. The study was carried out prospectively after approval by the Ethics Committee of the University of Heidelberg and in concordance with the Declaration of Helsinki. Written informed consent was obtained from all persons.

Echocardiography

All echocardiographic examinations were performed on a commercially available ultrasound machine (Vivid E9 BT 11; GE Vingmed Ultrasound AS, Horten, Norway) according to the guidelines of the American Society of Echocardiography[2,7] and using a 1.5- to 4.6-MHz phased-array probe (M5S-D) for 2D imaging and an active-matrix four-dimensional volume phased-array probe (4V-D) for 3DE. Image acquisition was conducted in a breath-hold manner, and at least three consecutive heart cycles were recorded after passive end-expiration. The LV endocardium was used as the boundary for volumetric measurements. Papillary muscles and visible trabeculae were part of the blood pool. If endocardial border detection was uncertain, nonvisible parts were interpolated manually. Three different techniques were used to determine LV volumes and function:

1. The modified biplane Simpson's method, as recommended by the American Society of Echocardiography[2]: End-diastolic and end-systolic endocardial borders were traced manually on frozen 2D images obtained from the apical two- and four-chamber views to derive end-diastolic volume (EDV) and end-systolic volume (ESV). The LV EF was calculated according to the formula $EF = (EDV - ESV)/EDV \times 100\%$.
2. The Auto-EF tool (EchoPAC version 110.1.1 BT 11; GE Vingmed Ultrasound AS)[3]: Using dynamic 2D images of the apical four- and two-chamber views, three anchor points were set within the LV cavity, two at the level of the mitral valve annulus and one at the LV apex. Endocardial borders were then detected and traced automatically by the software during a whole heart cycle to calculate EDV, ESV, and EF. When needed, corrections could be carried out manually (Figure 2A).
3. Three-dimensional echocardiographic analysis using the 4D Auto LVQ tool (EchoPAC version 110.1.1 BT 11; GE Vingmed Ultrasound AS, Trondheim, Norway)[4]: Three-dimensional data sets were acquired, comprising the whole heart in a 90° × 90° pyramidal scan volume and were recorded during breath-hold in passive end-expiration. A multibeat mode over up to six heart cycles was used to achieve high temporal resolution, with frame rates between 30 and 50 frames/sec. After data acquisition, fully automated orientation of the apical four-chamber, two-chamber, and long-axis planes was attempted. Orientation was manually adjusted if needed. Two points were then manually set in end-diastole as well as in end-systole, one at the level of the mitral valve, one at the LV apex, to define basal and apical limits of the LV cavity. Endocardial borders were detected, and values of EDV, ESV, and EF then calculated automatically by the software. Automatic endocardial border detection was manually corrected if the software excluded papillary muscles or visible trabeculae from the LV cavity (Figure 2B).

CMR Imaging

A whole-body CMR scanner (1.5-T Achieva; Philips Medical Systems, Best, The Netherlands) was used for image acquisition, applying a short-axis multislice cine steady-state free precession sequence with parallel imaging (8–12 slices; slice thickness, 8 mm; gap, 2 mm; ≥35 phases per cardiac cycle; balanced fast field echo; repetition time, 2.9 msec; echo time, 1.45 msec; reconstructed voxel size, 1.5 × 1.5 × 8 mm acquisition; sensitivity encoding factor, 2). According to recent guidelines,[5] the LV cavity, defined as the border between compacted and noncompacted myocardium, was manually traced in each short-axis slice in end-diastole and end-systole (Figure 2C) with a commercially available software package to calculate EDV, ESV, and EF (Extended MR Workspace version 2.6.3.4; Philips Medical Systems). Papillary muscles were part of the blood pool.

Statistical Analysis

Statistic analysis was carried out with the SigmaStat version 3.5 (Systat Software, Inc, Chicago, IL), and graphs were drawn with GraphPad