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ORIGINAL RESEARCH

Transthoracic 3D Echocardiographic Left Heart Chamber Quantification Using an Automated Adaptive Analytics Algorithm

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ABSTRACT

OBJECTIVES The goal of this study was to test the feasibility and accuracy of an automated algorithm that simultaneously quantifies 3-dimensional (3D) transthoracic echocardiography (TTE)-derived left atrial (LA) and left ventricular (LV) volumes and left ventricular ejection fraction (LVEF). Conventional manual 3D TTE tracings and cardiac magnetic resonance (CMR) images were used as a reference for comparison.

BACKGROUND Cardiac chamber quantification from 3D TTE is superior to 2D TTE measurements. However, integration of 3D quantification into clinical practice has been limited by time-consuming workflow and the need for 3D expertise. A novel automated software was developed that provides LV and LA volumetric quantification from 3D TTE datasets that reflect real-life manual 3-dimensional echocardiography measurements and values comparable to CMR.

METHODS A total of 159 patients were studied in 2 separate protocols. In protocol 1, 94 patients underwent 3D TTE imaging (EPIQ, iE33, X5-1, Philips Healthcare, Andover, Massachusetts) covering the left atrium and left ventricle. LA and LV volumes and LVEF were obtained using the automated software (HeartModel, Philips Healthcare) with and without contour correction, and compared with the averaged manual 3D volumetric measurements from 3 readers. In protocol 2, automated measurements from 65 patients were compared with a CMR reference. The Pearson correlation coefficient, Bland-Altman analysis, and paired Student *t* tests were used to assess inter-technique agreement.

RESULTS Correlations between the automated and manual 3D TTE measurements were strong ($r = 0.87$ to 0.96). LVEF was underestimated and automated LV end-diastolic, LV end-systolic, and LA volumes were overestimated compared with manual measurements. Agreement between the automated analysis and CMR was also strong ($r = 0.84$ to 0.95). Test-retest variability was low.

CONCLUSIONS Automated simultaneous quantification of LA and LV volumes and LVEF is feasible and requires minimal 3D software analysis training. The automated measurements are not only comparable to manual measurements but also to CMR. This technique is highly reproducible and timesaving, and it therefore promises to facilitate the integration of 3D TTE-based left-heart chamber quantification into clinical practice. (J Am Coll Cardiol Img 2016;9:769–82)

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ABBREVIATIONS AND ACRONYMS

2D = 2-dimensional

3D = 3-dimensional

3DE = 3-dimensional echocardiography

CMR = cardiac magnetic resonance

CT = computed tomography

LA = left atrium

LAV = left atrial volume

LV = left ventricle

LVEDV = left ventricular end-diastolic volume

LVEF = left ventricular ejection fraction

LVES = left ventricular end-systole

LVESV = left ventricular end-systolic volume

TTE = transthoracic echocardiography

Multiple studies have demonstrated the advantages of using 3-dimensional echocardiography (3DE). Specifically, 3-dimensional (3D) transthoracic echocardiographic (TTE) measurements of left ventricular (LV) and left atrial (LA) volumes are superior in accuracy and reproducibility to 2-dimensional (2D) techniques, due to avoidance of geometric assumptions and foreshortened views (1–3). These findings have led to guidelines supporting the clinical use of 3DE in LV volume assessment (4,5). In addition, 2D and 3DE datasets can now be acquired by using a single transducer, allowing the integration of 3DE into routine practice.

Despite these demonstrated benefits, however, widespread use of 3D TTE for LA and LV volume assessments has not become a clinical reality. This scenario is likely due to the time and training required to obtain accurate and reproducible 3DE volumetric measurements (1,6,7). The availability of a reasonably accurate and reproducible, automated cardiac chamber quantification technique, which would require minimal or no manual correction of endocardial borders, would potentially allow integration of 3DE volumetric LV and LA measurements into routine practice.

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Novel automated software has been developed that provides LV and LA volumetric quantification. Because 3DE-derived volumes are known to be smaller than those obtained from cardiac magnetic resonance (CMR) images, the program was designed to provide 2 types of 3DE LV and LA volumes: values reflective of real-life manual 3DE measurements (3DE model) and values comparable to CMR (CMR model). The present study was designed to: 1) validate automated LV and LA measurements obtained by using the 3DE model against manual 3DE measurements and those obtained using the CMR model against the CMR reference; 2) examine the relationship between LV and LA measurements obtained by using these techniques; and 3) compare the reproducibility and analysis time of the 3DE model with those of the conventional manual 3DE measurements.

METHODS

All studies were performed at the University of Chicago Medical Center. The institutional review board approved the protocol. Written informed consent was obtained for each patient. 3DE imaging was performed using an EPIQ/iE33, X5 transducer (Philips Healthcare, Andover, Massachusetts) with the patient in the left lateral decubitus position. Wide-angled acquisition using "full-volume" mode over 4 consecutive cardiac cycles was used during a single breath-hold. Care was taken to include the entire LA and LV cavity within the 3D volume. Imaging settings were optimized for endocardial visualization. The highest possible frame rate was obtained by minimizing imaging depth and sector width.

PROTOCOL 1: 3DE MANUAL REFERENCE STANDARD. To validate the automated 3DE model, we compared left ventricular end-systolic volumes (LVESV), left ventricular end-diastolic volumes (LVEDV), left ventricular ejection fraction (LVEF), and left atrial volumes (LAV) at left ventricular end-systole (LVES) obtained from the automated 3DE program versus 3D manual measurements. Patients were included if they were in sinus rhythm and agreed to participate. Patients were excluded if they had poor endocardial visualization on 2D echocardiography of ≥3 contiguous segments using a 17-segment model or complex congenital heart disease.

We screened 104 consecutive patients who were referred for 2D TTE for assessment of LV function and had no history of mitral valve replacement or right heart enlargement. After excluding 10 patients because of poor image quality, 94 patients were studied. Two independent investigators analyzed the 3DE datasets using the prototype-automated software, and their results were averaged.

Three additional independent expert investigators manually measured the 3DE datasets to obtain LVESV, LVEDV, LVEF, and LAV at LVES. Manual measurements were then averaged and used as a manual reference standard that was not biased by an individual measurement style but reflected real-world variability. Individuals involved in the development of the program did not participate in the analysis of the validation datasets.

PROTOCOL 2: CMR REFERENCE STANDARD. To validate the automated CMR model against a CMR reference standard, 69 nonconsecutive patients referred for CMR evaluation, who agreed to undergo transthoracic 3DE within 24 h of the CMR study, were recruited by using inclusion and exclusion criteria identical to those in protocol 1. Of the 69 patients, 4 were excluded because of poor TTE image quality. In the remaining 65 patients, LV and LA automated 3DE measurements were compared with CMR values. In addition, as in protocol 1, 3 independent expert investigators manually measured the 3DE datasets to obtain LVESV, LVEDV, LVEF, and LAV at LVES. The