Ultrasound in Med. & Biol., Vol. 00, No. 00, pp. 1–9, 2018

0301-5629/$ - see front matter

https://doi.org/10.1016/j.ultrasmedbio.2018.07.015

● *Original Contribution*

MEASUREMENT OF LEFT VENTRICULAR VOLUMES AND EJECTION FRACTION IN PATIENTS WITH REGIONAL WALL MOTION ABNORMALITIES USING AN AUTOMATED 3D QUANTIFICATION ALGORITHM

QIZHE CAI, JIANGTAO WANG, HONG LI, CHENG LI, XIAOPENG WU, and XIUZHANG LU
Department of Echocardiography, Heart Center, Beijing Chao Yang Hospital, Capital Medical University, Beijing, China

(*Received* 22 *January* 2018; *revised* 30 *June* 2018; *in final from* 16 *July* 2018)

Abstract—Accurate and rapid left ventricular (LV) ejection fraction (EF) measurement is crucial for patients with wall motion abnormalities (WMAs). Conventional 2D echocardiographic imaging has limitations. The recently developed software HeartModel (HM, Philips Healthcare, Andover, MA, USA) has shown promise in automated 3D quantification. However, the accuracy and detailed features of HM in measurements of LV volume and EF in patients with regional WMAs have not been carefully investigated. In the present study, echocardiographic imaging (EPIQ, X5-1, Philips Healthcare) was performed in 72 patients with WMAs. The LV end-diastolic volume (EDV), end-systolic volume (ESV) and EF were measured by HM in three modes: without editing and with global and regional endocardial border editing (Auto 3D-NE, Auto 3D-GE and Auto 3D-RE, respectively). The conventional 2D Simpson's biplane method and manual 3D quantification (QLAB-3DQA software, Philips Healthcare), as the standard method, were used for comparison. Among the three HM modalities, Auto 3D-RE exhibited the best correlation with manual 3D in assessing EDV, ESV and EF ($r = 0.88$, 0.93 and 0.91, respectively), although it took slightly longer (67.3 ± 13.0 s). Auto 3D-RE also exhibited a small degree of bias for the measurements (EDV: 11.7 mL, ESV: 8.45 mL, EF: −1.57%) and narrow limits of agreement. Heterogeneity of LV wall motion was defined to indicate the dispersion degree of WMAs. It associated with the difference in EF measurement between Auto 3D-RE and manual 3D ($p = 0.014$, hazard ratio = 5.19). In patients with WMAs, HM with regional contour editing enables accurate and efficient evaluation of LV volume and EF. (E-mail: lxz_echo@163.com)

Key Words: ***A*utomated algorithm, 3D echocardiography, wall motion abnormalities.**

INTRODUCTION

In clinical practice, the class I recommendations for the evaluation of cardiac systolic function and structure in patients with wall motion abnormality (WMA) include measurement of left ventricular (LV) ejection fraction (EF) and volume (O'Gara et al. 2013; Roffi et al. 2016). Conventionally, these two key parameters are measured with Simpson's biplane 2D echocardiographic method. However, this method has several drawbacks including apical foreshortening and reliance on geometric assumptions. The incapability to track all LV segments significantly affects the quantification (Lang et al. 2012). In contrast to the 2D method, manual 3D echocardiography (Manual 3D) has been found to provide accurate quantification, comparable to that obtained with cardiac magnetic resonance (CMR) imaging (Dorosz et al. 2012; Lang et al. 2012). The acquisition of full-volume data sets using Manual 3D, however, requires the regrouping of four cardiac circles into a full view and further manual tracing. Both of the processes are time consuming, which restricts its usage in clinical practice. Thus, an efficient algorithm is highly desirable.

Recently, there have been studies examining biomedical applications of artificial intelligence and machine learning. Many algorithms have been developed to aid disease detection and diagnosis (Esteva et al. 2017; Gulshan et al. 2016). Automated algorithms dedicated to cardiac image analysis are now rapidly evolving (Knackstedt et al. 2015; Slomka et al. 2017). HeartModel (HM, Philips Healthcare, Andover, MA, USA) is one of the new automated algorithms that is able to quantify LV and atrial volumes in 3D echocardiography. It enables simultaneous automatic analyses of LV

Address correspondence to: Xiuzhang Lu, Echo Department, Heart Center, Beijing Chao-Yang Hospital, Capital Medical University, 8 Gongren Tiyuchang Nanlu, Beijing 100020, China. E-mail: lxz_echo@163.com

end-diastolic volume (EDV), end-systolic volume (ESV) and LVEF with no manual editing (designated Auto 3D-NE mode). The software, in addition, provides two editing modalities, global and regional editing (designated Auto 3D-GE and Auto 3D-RE, respectively) to improve the accuracy of automated tracing. HM has shown promise in the measurement of LV volume and EF in patients with sinus rhythm (Tsang et al. 2016) and atrial fibrillation (Yang et al. 2016). The quantification results of Auto-3D also correlated well with those obtained with Manual 3D in LV volume assessment (van den Hoven et al. 2017; Otani et al. 2016; Tamborini et al. 2017). A recent multicenter study reported that the reproducibility of the HM algorithm was similar to or better than that of the conventional Manual 3D (Medvedofsky et al. 2018). However, these studies either enrolled only a small group of patients with WMAs (Tamborini et al. 2017) or excluded patients with aneurysms (Medvedofsky et al. 2018). Whether Auto 3D yields results comparable to those of Manual 3D in a larger group of WMA patients requires further investigation.

One of the essential factors influencing the modeling of all the automated 3D algorithms is the alteration of heart shape that is commonly seen in many diseases such as myocardial infarction, heart diverticulum and Takotsubo cardiomyopathy. As patients with WMAs undergo morphologic changes in LV chamber or contraction dyssynchrony of lesion segments, the necessity for border editing and suitable editing modalities of Auto 3D are worth evaluating. Thus, using HM as an example, we here investigate the features of the Auto 3D method in quantification of LV volume and LVEF for patients with WMAs. Given that Manual 3D yields results comparable to those of the gold standard CMR imaging, we compare the accuracy of the three modalities (Auto 3D-NE, Auto 3D-GE and Auto 3D-RE) of HM with Manual 3D. We further investigate the factors that potentially influence the quantification accuracy in those patients

METHODS

Study population

Seventy-two patients with histories of myocardial infarction who attended the outpatient department of Beijing Chao-Yang Hospital between September 2016 and May 2017 were considered for study inclusion. The exclusion criteria were (i) fewer than 14 visible endocardial border segments, (ii) arrhythmia, (iii) congenital heart disease and (iv) presence of a prosthetic valve. The institutional review board and ethics committee of Beijing Chao-Yang Hospital approved the study protocol. Informed consent was obtained from all participants.

Echocardiographic image acquisition and analysis

Transthoracic echocardiographic (TTE) images were acquired in the Department of Echocardiography of Beijing Chao-Yang Hospital with an EPIQ 7C scanner (Philips Healthcare, Andover, MA, USA) equipped with a matrix-array transducer (X5-1), HM and QLAB-3DQA software (Philips Healthcare, Andover, MA, USA). Two experienced echocardiography physicians collected and analyzed all images. The durations of image acquisition and analyses were recorded for each patient.

Conventional echocardiographic method. Biplane images were analyzed online with the EPIQ 7C system. Biplane LV images were obtained using the X-plane function with the angle adjusted to 0˚ and 120˚ to display four- and two-chamber views simultaneously. The endocardium was traced manually in the end-diastolic and end-systolic frames. For analysis, the end-diastolic and end-systolic frames were defined as the frames at the R-wave peak and T-wave end, respectively.

Manual 3D method. Four-beat full-volume 3D data sets were collected using the apical approach during breathhold and measured manually. All images were adjusted in depth, width and resolution to guarantee the highest possible frame rates. The QLAB-3DQA software was used for manual measurement. End-diastolic and end-systolic frames were determined by the evaluator according to the procedures described later. In four- and two-chamber views, four hinge points (septal, lateral, anterior and inferior) were placed on the mitral annulus, and the apical points were identified in both views. The software connected the hinge points and traced the endocardial border preliminarily. Manual correction was then performed to trace the actual border and to calculate the EDV, ESV and EF.

Automated 3D method. Automated 3D quantification was performed using HM software. Three-dimensional data sets were collected using the apical approach and analyzed by the software. The LV endocardium was automatically identified based on about 1000 3D TTE images, including those of left hearts with various morphologies and status (Tsang et al. 2016). It simultaneously depicted the left heart in four-, three- and two-chamber views and automatically defined the LV endocardial border with no editing (Auto 3D-NE mode). Global and regional editing were also performed (Auto 3D-GE and Auto 3D-RE modes, respectively) to optimize the fit of the automated tracing border and native endocardial border. All three modes were used to analyze LV volume and EF in patients with WMAs.