Feasibility of One-Beat Real-Time Full-Volume Three-Dimensional Echocardiography for Assessing Left Ventricular Volumes and Deformation Parameters

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Background: Real-time three-dimensional echocardiographic (3DE) imaging usually requires multibeat acquisition to maintain high temporal and spatial resolution for full-volume data sets. However, this procedure generates stitch artifacts in patients with irregular heartbeats; thus, one-beat acquisition might be useful. The aim of this study was to compare the efficacy of using new-generation one-beat full-volume acquisition for measuring left ventricular (LV) mechanical parameters with that of four-beat acquisition.

Methods: In protocol 1, 34 patients who had undergone both cardiac magnetic resonance and 3DE imaging on the same day were prospectively enrolled. In protocol 2, 115 patients in sinus rhythm who had undergone 3DE examinations were retrospectively enrolled. LV volume, ejection faction, and global strain were measured using one-beat and four-beat 3DE data sets. In protocol 3, 26 patients with atrial fibrillation who had acquisition of consecutive one-beat full-volume data sets were retrospectively enrolled, and it was determined whether the LV parameters in the index beat were correlated with corresponding average values obtained from multiple one-beat acquisitions.

Results: In protocol 1, the correlations between LV volumes and LV ejection fraction between cardiac magnetic resonance and 3DE imaging with one-beat acquisition were excellent (r = 0.91-0.93). In protocol 2, correlations were also excellent (r = 0.94-0.99), and there were no significant differences in volume rate, LV volumes, LV ejection fraction, and global strain parameters between one-beat and four-beat acquisition data sets. In protocol 3, correlations were excellent (r = 0.94-0.99) between LV parameters from the index beat and corresponding average values.

Conclusions: Three-dimensional echocardiographic full-volume data sets with one-beat acquisition not only maintained volume rate but also provided LV mechanical parameter values similar to those obtained using multibeat acquisition. Using one-beat acquisition for patients with atrial fibrillation expands its clinical applicability. (J Am Soc Echocardiogr 2016;■:■-■.)

Keywords: Three-dimensional echocardiography, Left ventricle

Echocardiographic assessment of left ventricular (LV) function—volume, LV ejection fraction (LVEF), and myocardial deformation parameters—is the cornerstone of clinical decision making given its valuable information for early diagnosis, management decisions, and prognosis.[1,2] Unrelenting efforts, therefore, have been made to provide accurate, reproducible, and convenient methods for LV analysis.[3]

Traditional two-dimensional (2D) echocardiographic imaging has inherent limitations caused by geometric assumptions, foreshortening, and an inability to track through-plane motion in volume and deformation analysis.[2,4] Advances in three-dimensional (3D) echocardiographic (3DE) imaging in the past few decades undoubtedly permit more comprehensive assessments of LV mechanics in 3D space. For instance, 3D full-volume data sets efficiently provide more information than do multiple 2D cut-plane acquisitions, because all of the LV myocardium is simultaneously displayed. The accuracy of 3DE imaging compared with cardiac magnetic resonance (CMR) has also been validated in several studies.[5,6] However, current 3DE full-volume data acquisition requires multibeat data acquisition to create full-volume data sets with high temporal and spatial resolution, which sometimes produces stitching artifacts, particularly in patients with irregular heart rhythms and those who cannot control their respiration.[2] To overcome this obstacle and broaden the clinical use of 3DE imaging, researchers have explored the feasibility of acquiring one-beat full-volume data sets with a relatively high volume rate.[7,8] This breakthrough is promising and might usher 3DE imaging into mainstream use.

Therefore, in the present study we sought to (1) validate the accuracy of LV volume and LVEF measurements using 3DE full-volume data sets with one-beat acquisition against CMR as a reference, (2) compare LV

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Abbreviations

AF = Atrial fibrillation

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

3D = Three-dimensional

3DE = Three-dimensional echocardiographic

2D = Two-dimensional

vps = Volumes per second

mechanical parameters with one-beat 3DE data sets with the same parameters analyzed using four-beat 3DE data sets, and (3) determine the usefulness of one-beat 3DE in patients with atrial fibrillation (AF).

METHODS

Study Population

The study was divided into three protocols, all of which were done at the University of Occupational and Environmental Health Hospital (Kitakyushu, Japan) between August 21, 2015, and March 22, 2016. The hospital's ethics committee approved the study protocol, and informed consent was obtained from all study patients.

In protocol 1, 34 consecutive patients who had undergone clinically indicated CMR examinations and agreed to undergo 3DE studies on the same day were prospectively enrolled to determine the accuracy of one-beat acquisition for the measurement of LV volumes and LVEF against CMR as a reference. In protocols 2 and 3, 141 patients who had undergone 3DE imaging with both one-beat and four-beat acquisitions were retrospectively enrolled. One hundred fifteen patients were in sinus rhythm, and 26 had AF. From the patients with AF, we acquired one-beat 3DE full-volume data sets in 10 to 20 consecutive beats, which enabled us to determine the index beat and to calculate the average values from each single beat.

CMR Acquisition and Analysis

CMR imaging was done using a 3-T scanner (Discovery MR750W; GE Healthcare, Milwaukee, WI) with a phased-array cardiovascular coil. For each patient, retrospective electrocardiographically gated localizing spin-echo sequences were used to identify the long axis of the heart. Steady-state full-precision dynamic gradient-echo cine loops were acquired using retrospective electrocardiographic gating and parallel imaging techniques during 10- to 15-second breath-holds, with the following general parameters: 8-mm-thick imaging plane slices, 40×40 cm field of view, 200×160 scan matrix, 50° flip angle, 3.8-msec repetition time, 1.7-msec echo time, 20 views per segment, and 20 reconstructed cardiac phases. The LV endocardial border was manually traced at the end-diastolic and end-systolic frames in multiple short-axis steady-state free precession images.[9] LV volumes were determined using the disk area summation method, and LVEF was calculated using a standard formula with validated analysis software (Segment version 2.0; Medviso, Lund, Sweden).[10]

Three-Dimensional Echocardiography

Real-time 3DE full-volume data sets were acquired from the apical window with the patient in the left lateral decubitus position using an EPIQ 7G scanner (Philips Medical Systems, Andover, MA) equipped with a fully sampled matrix-array transducer (X5-1). The gain and compression were adjusted to minimize dropout of the LV myocardial borders. The depth and sector angle were adjusted to include the entire left ventricle. At least three full-volume data sets throughout one cardiac cycle were obtained using one-beat acquisition as well as four-beat acquisition. For one-beat acquisition, we used HMQ acquisition mode to maintain a high volume rate. In patients with AF, we used one-beat acquisition mode and acquired consecutive cardiac beats ranging from 10 to 20 cardiac cycles on the basis of each patient's breath-holding ability. Three-dimensional echocardiographic full-volume data sets were stored on a hard disk for offline analysis.

Three-Dimensional Echocardiographic Analysis of LV Volumes and Strain

Three-dimensional echocardiographic full-volume data sets were analyzed by an experienced investigator using vendor-independent 3D speckle-tracking software (4D LV Analysis version 3.1.2; TomTec Imaging Systems, Unterschleissheim, Germany). The most appropriate 3D full-volume one-beat or four-beat data set, which encompassed the whole left ventricle, was selected for analysis. After the data sets had been retrieved, the apical four-chamber, two-chamber, long-axis, and short-axis views in the end-diastolic frames were automatically extracted. Nonforeshortened apical views were identified to select the point of the apex and the center of the mitral annular line connecting both sides of the mitral annulus with the largest LV long-axis dimensions, after which the 3D endocardial surface was automatically reconstructed. The endocardial surfaces were manually adjusted when necessary. The same procedure was used for the end-systolic frame. When tracking was deemed inadequate, the endocardial surface was manually traced as necessary. Subsequently, the software was used for 3D speckle-tracking analysis throughout the cardiac cycle. The software generates time-domain LV volume curves, from which the LV end-diastolic volume (LVEDV), end-systolic volume (LVESV), and LVEF were automatically determined. For 3D strain analysis, the left ventricle was divided into 16 segments using standard segmentation schemes. The software provided averaged longitudinal, circumferential, and radial strain time curves from each segment, from which peak global strain values were automatically obtained.[11]

In protocol 1, another experienced physician blinded to the results of manual 3DE analysis analyzed 3DE LV volumes and LVEF using an automated adaptive program (Heart Model; Philips Medical Systems) in different one-beat acquisition images that encompassed the entirety of the four cardiac chambers, because Heart Model analysis requires that all four cardiac chambers be visualized in the one-beat acquisition full-volume data sets. The software automatically displays the LV contour on end-diastolic and end-systolic 2D cutting planes (apical four-, two-, and three-chamber views) and provides LVEDV, LVESV, and LVEF. The endocardial borders were manually edited when the user was not satisfied with the automated LV contour.

Image quality was assessed by summing the scores given in each of the 18 segments of three apical views; the following algorithm was used: (1) 0 point = more than half of the endocardium is invisible, (2) 1 point = less than half of the endocardium is invisible, and (3) 2 points = the entire endocardium is clearly visible. Image quality was defined as good if its score ranged between 28 and 36 and poor if it was ≤27.[12]

Three-Dimensional Echocardiographic Analysis in AF

LV mechanical parameters were measured using the same 3D speckle-tracking software in each consecutive beat in all patients, and average values were determined for each patient. To determine the index beat, we measured the preceding RR interval (RR1) and