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Original article

Feasibility of left ventricular volume measurements by three-dimensional speckle tracking echocardiography depends on image quality and degree of left ventricular enlargement: Validation study with cardiac magnetic resonance imaging

Ryo Kawamura (MD)[a], Yoshihiro Seo (MD, PhD, FJCC)[a,*], Tomoko Ishizu (MD, PhD, FJCC)[a], Akiko Atsumi (MD)[a], Masayoshi Yamamoto (MD)[a], Tomoko Machino-Ohtsuka (MD)[a], Hideki Nakajima (PhD)[a], Satoshi Sakai (MD, PhD)[a], Yumiko Oishi Tanaka (MD, PhD)[b], Manabu Minami (MD, PhD)[b], Kazutaka Aonuma (MD, PhD, FJCC)[a]

[a] *Cardiovascular Division, University of Tsukuba, Tsukuba, Japan*
[b] *Department of Radiology, University of Tsukuba, Tsukuba, Japan*

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ABSTRACT

Background: Novel 3-dimensional echocardiography with speckle tracking imaging (3D-STE) may have advantages in assessing left ventricular (LV) volume through a cardiac cycle. The feasibility of 3D-STE may be affected by image quality and LV morphology.
Methods and results: We studied 64 patients (38 men, age 55 ± 12 years) who underwent cardiac magnetic resonance imaging (CMRI) and 3D-STE on the same day. LV end-diastolic volume (EDV) and end-systolic volume (ESV) were measured by both modalities. Imaging qualities were quantified in each of 6 LV segments by an imaging quality score (IQS) of 1–3, and scores were averaged (mean IQS) at end-diastole and end-systole. Compared to CMRI, 3D-STE showed a tendency to underestimate LV volume measurements, but not significantly (EDV: bias = −18 ± 37 ml; ESV: bias = −10 ± 34 ml), and measurements correlated well with those by CMRI (EDV: $R = 0.80$, ESV: $R = 0.86$, ejection fraction: $R = 0.75$, $p < 0.001$). The absolute differences of LVEDV and ESV between 3D-STE and CMRI correlated significantly with mean IQS (LVEDV, $R = -0.35$, $p = 0.005$; LVESV, $R = -0.30$, $p = 0.02$). Based on the medium value of LVEDV by CMRI (127 ml), subjects were classified into the small (<127 ml) and large LVEDV (≧127 ml) groups. In the large LVEDV group, mean IQS significantly correlated with the absolute differences of LVEDV (mean IQS, $r = -0.45$, $p = 0.01$), despite no significant correlation in the small LVEDV group.
Conclusion: 3D-STE could measure LV volume as well as CMRI, however, its accuracy depends on the quality of the acquired image and particularly on enlargement of the left ventricle.

Introduction

One limitation of conventional 2-dimensional (2D) echocardiography is the "through plane" phenomenon. Because the entire heart is moving in various directions at the same time, the fixed cross-sectional echo window permits only faulty measurements [1–5]. In contrast, 3-dimensional (3D) echocardiography may compensate for this limitation by obtaining 3D information [6–8]. We have previously validated left ventricular (LV) strain measurements by 3D speckle tracking echocardiography (3D-STE) in an animal model [9]. In principle, however, acquiring and analyzing 3D data requires more computational resources, and that gives rise to more restrictions in spatial and temporal resolution compared with 2D echocardiography. Accordingly, this may cause substantially inadequate precision. Nesser et al. [10] validated the ability of 3D-STE to measure LV volume in a comparison study with cardiac magnetic resonance imaging (CMRI). They reported favorable accuracy and reproducibility over measurements by 2D echocardiography, but they limited their analysis to subjects with adequate imaging quality. However, it is not always possible to expect acceptable imaging quality, which may affect actual results of measurements in the real-world clinical setting. Therefore, the aims of this study of consecutive patients who underwent CMRI were: (1) to compare LV volume measurements between 3D-STE and CMRI and (2)

* Corresponding author at: Cardiovascular Division, Faculty of Medicine, University of Tsukuba, 1-1-1 Tennodai, Tsukuba 305-8575, Japan. Tel.: +81 298 53 3143; fax: +81 298 53 3143.
E-mail address: yo-seo@md.tsukuba.ac.jp (Y. Seo).

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to evaluate factors that relate to the differences of LV volume measurements between 3D-STE and CMRI.

Methods

Study subjects

This study enrolled 68 consecutive patients who underwent echocardiographic examination within 1 h after CMRI examination. The intrinsic cardiac rhythm in all patients was sinus rhythm. The study was approved by the local research ethics committee, and all patients gave their written informed consent.

Conventional LV volume measurements

All echocardiographic data was obtained with an Aplio Artida™ echocardiographic system (Toshiba Medical Systems, Tochigi, Japan). In conventional 2D echocardiographic examinations, LV end-diastolic volume (LVEDV) and end-systolic volume (LVESV) were measured by the bi-plane modified Simpson's method [11].

LV volume measurements by 3D-STE

All 3D echocardiographic examinations also were performed with the Artida™ ultrasound system. Full-volume electrocardiogram (ECG)-gated 3D data sets were acquired from apical positions using a matrix array 2.5-MHz transducer. To obtain these data sets, 6 sectors were scanned and automatically integrated into a wide-angle ($70^\circ \times 70^\circ$) pyramidal data image covering the entire LV. Frame rate of each image was set at approximately 30 Hz.

The data were stored and transferred to a personal computer-based workstation for off-line analysis. The images were analyzed with the Advanced Cardiology Package software (Toshiba Medical Systems Co.) specifically designed for analysis of data acquired with the Artida™ system. A representative case is shown in Fig. 1. The 3D data sets were displayed as multiplanar reconstruction (MPR) images corresponding to apical 2-chamber and 4-chamber views and 3 short-axis levels. In the MPR display, the ventricular long axis was adjusted so that the longest chamber lengths for the 4-chamber view in panel A and 2-chamber view in panel B of Fig. 1 were obtained. After adjustment of the planes, the endocardial contours were traced for the respective views. Each contour was verified in the reconstructed short-axis views at the levels of the apical, mid, and basal sections in panels C3, C5, and C7, respectively, so that the contour exactly traced the endocardium. The papillary muscles were not included in the LV cavity. The 3D-STE system automatically followed the transformation of the left ventricle during the measured cardiac cycle, and the transitions of the LV contour were verified visually throughout the cardiac cycles. If this procedure failed to track the transition of the wall motion, the procedure was repeated until valid tracings were obtained. LV volume was measured directly from the tracked 3D endocardial surface information obtained by 3D-STE, and volumes were obtained from a single cardiac cycle with no assumptions about LV structure. LVEDV was defined as the LV volume at end-diastole, and LVESV was defined as the minimum LV volume measured during the cardiac cycle. LV ejection fraction (LVEF, %) was calculated by the formula $(\text{LVEDV} - \text{LVESV}) \times 100/\text{LVEDV}$ [9].

Quantification of 3D-STE imaging quality

3D-STE imaging quality was classified into 3 states according to the feasibility of determining segmental endocardial continuity by defining an imaging quality score (IQS). Score 3 indicates that the contour is clearly visible and easily traced, score 2 indicates that the contour is not clearly visible but can be determined from the echo information of adjacent tissue, and score 1 indicates that the contour can hardly be seen. In Fig. 1, the apical 2-chamber view was divided into 3 combined regions: first, combined with basal and mid anterior walls; second, apical anterior and apical inferior walls, and third, basal and mid inferior walls. Similarly, in the apical 4-chamber view, the image was divided into 3 combined regions: first, combined with basal and mid lateral walls; second, apical lateral and apical septal walls; and third, basal and mid septal walls. Each region was evaluated at the end-diastolic and end-systolic phases by two different experienced observers (R.K., Y.S.). Image quality was calculated as the mean total score (mean IQS) of the scores assessed at end-diastole and at end-systole. An example of scoring at end-diastole is shown in Fig. 2.

CMRI acquisition

CMRI examinations were performed with a 1.5-T superconducting unit (NT/Intera 1.5 T Master R12; Philips, Best, Netherlands) with a phased-array cardiac coil. First, ECG-gated cine mode images with a steady-state free precession (balanced turbo field echo) were obtained in long- and short-axis views of the left ventricle at 10-mm slice thickness without an intersection gap. The repetition time and echo time were 2.845 and 1.4225 ms, respectively, the flip angle was 70°, and the imaging matrix was 160×229. Acquisition time was from 10 to 16 s long during breath holding.

CMRI analysis

The images obtained by the CMRI scanner were stored on an optical disk in DICOM format. The data were analyzed off-line with a personal computer-based system using commercial analysis software (ViewForum R5.1V1L1; Philips). The software loaded serial short-axis sections of the left ventricle, and the first basal slice, which showed the circular LV wall construction throughout the cardiac cycle, and the last apical slice, which showed the LV cavity, were set manually. In the end-diastolic frame of the first slice, the inner contour was manually traced, and the software automatically recognized the contour of subsequent frames. The same procedure was performed on each slice until the final apical slice. If incorrect tracing was apparent, the contour was corrected manually in the appropriate frames. The intraventricular volume was calculated as the total sum of the product of the area within each contour and the thickness between the each slice (i.e. 10 mm). The EDV was set as the volume at the time of R-wave onset on the ECG, and the ESV was set as the smallest volume measured throughout the cardiac cycle. These data were used as the reference values for echocardiographic measurements.

Reproducibility analysis

Reproducibility of the measurements from both modalities was determined by analyzing random samples from 10 cases by the same investigator at least 1 month after the first analysis to determine intra-observer variability and by a separate investigator (H.N.) to determine inter-observer variability. The other investigator was blinded to the results of the first observer. Reproducibility was analyzed as the coefficient of variability defined as the ratio of the standard deviation (SD) and the mean of absolute readings for each echocardiographic parameter.

Statistical analyses

Results are expressed as number or the mean value ± SD. The echocardiographic data were compared with the data obtained from CMRI as the reference. The data were statistically analyzed