Quantitative validation of left atrial structure and function by two-dimensional and three-dimensional speckle tracking echocardiography: A comparative study with three-dimensional computed tomography

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A B S T R A C T

Background: The aim of this study was to validate the accuracy of three-dimensional (3D) speckle tracking echocardiography (STE) and two-dimensional (2D)-STE for the assessment of left atrial (LA) volume and function by comparison with 3D-computed tomography (CT) performed on the same day as STE.

Methods: LA phasic volume and emptying function (EF) were measured in 28 patients with paroxysmal atrial fibrillation undergoing catheter ablation (62 ± 11 years old) using both 3D-STE and 2D-STE during sinus rhythm. LA phasic volume and function measured by 3D-STE and 2D-STE were validated using 3D-CT as a gold standard.

Results: The intraobserver correlation coefficient and variability in maximum LA volume assessed by 3D-STE were 0.99 and 1.4 ± 6.0%, respectively. The interobserver correlation coefficient and variability in maximum LA volume assessed by 3D-STE were 0.99 and 0.2 ± 4.5%, respectively. There were strong correlations between LA phasic volume measured by 3D-CT and those measured by 3D-STE (r = 0.98, p < 0.001). There were correlations between LA phasic function measured by 3D-CT and those measured by 3D-STE (r = 0.85–0.88, p < 0.001). There was a better agreement between 3D-CT and 3D-STE in the assessment of LA phasic volumes and function than between 3D-CT and 2D-STE in apical 2- and 4-chamber view.

Conclusions: 3D-STE allows more accurate measurement of LA volume and function than 2D-STE and has high reproducibility.

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Introduction

Left atrial (LA) volume and function are thought to reflect left ventricular (LV) diastolic function and may serve as useful predictors of cardiovascular outcomes [1–3]. Thus, assessment of LA volume and function is important in the clinical setting. Recently, two-dimensional speckle tracking echocardiography (2D-STE) has been used to evaluate LA structure and function using Simpson’s method with the assumption of uniform geometry [4–6]. However, since cardiac motion is three-dimensional, 2D-STE is limited by the geometrical assumptions required to use Simpson’s method [5]. In contrast, three-dimensional speckle tracking echocardiography (3D-STE) has a major advantage in that there is improved accuracy in the evaluation of cardiac chamber volume without any geometrical assumptions [5–8]. For the left ventricle, 3D-STE was shown to be superior to 2D-STE for the measurement of LV volume and function [5–8]. However, there has been no study
of LA structure and function using 3D-STE. A previous validation study using a phantom reported that LA volume obtained by 3D-computed tomography (CT) was significantly correlated with true LA volume ($r=0.97$, $p<0.05$) and LA volume measured by 3D-CT was an accurate and feasible method [9]. Therefore, the purpose of this study was to validate the accuracy of 3D-STE for the measurement of LV volume and function using 3D-CT as a gold standard.

**Methods**

**Study population and study protocol**

LA phasic volume (maximum, pre-atrial contraction, and minimum volume) and LA phasic emptying function (EF) (total, passive, and active EF) in 28 patients with paroxysmal atrial fibrillation undergoing catheter ablation (19 men, mean age 62 ± 11 years) were measured using both 3D-STE and 2D-STE during sinus rhythm. Exclusion criteria were severe mitral regurgitation or stenosis, previous mitral valve surgery, permanent cardiac pacemaker implantation, elevated creatinine (>1.5 mg/dl), and iodine allergy. In addition, 2 subjects were excluded from the study because of poor echocardiographic recordings due to severe obesity or emphysema. LA phasic volume and function measured by 3D-STE and 2D-STE in apical 2- and 4-chamber view were compared with the values measured by enhanced 3D-CT performed on the same day as a gold standard in a blind manner to validate the STE measurement.

We calculated LA phasic function from time–LA volume curves during sinus rhythm. The time–LA volume curves were constructed in the apical 2- and 4-chamber views using 2D-STE and in the apical view using 3D-STE. These echocardiographic parameters measured by 3D-STE were compared with those obtained by 2D-STE from the apical 2- and 4-chamber views. LA total EF (reservoir function) was defined as (maximum LA volume – minimum LA volume)/maximum LA volume × 100%. LA passive EF (conduit function) was defined as (maximum LA volume – pre-atrial contraction LA volume)/maximum LA volume × 100%. LA active EF (booster pump function) was defined as (pre-atrial contraction LA volume – minimum LA volume)/pre-atrial contraction LA volume × 100%. Furthermore, LV ejection fraction, LV mass, and $E/e’$ were measured. Measurements were made using criteria recommended by the American Society of Echocardiography [10]. LV mass and LA volumes were indexed to body surface area. LV ejection fraction was calculated using Teichholz formula by M-mode echocardiography. LV mass was calculated at end diastole using the following formula: LV mass = $0.8 \times 1.04 \times [(LV dimension + LV posterior wall thickness + LV septal wall thickness)^2 – LV dimension^2] + 0.6$. Tissue Doppler measurement of mitral $e’$ wave velocity was made at the septal annulus. The present study was approved by the ethics committee of our institution and informed consent was obtained from all patients before enrollment.

![2D-Speckle Tracking](image1.png)

![3D-Speckle Tracking](image2.png)

**Fig. 1.** Representative image of two-dimensional speckle tracking echocardiography and three-dimensional speckle tracking echocardiography. Solid line: time–left atrial strain curve (%); broken line: time–left atrial volume curve (ml).
Two-dimensional and three-dimensional speckle tracking echocardiography

3D-STE (Artida, Toshiba Medical Systems, Tochigi, Japan) can provide a time–LA volume curve with a frame rate of 30–40 frames/s as well as 2D-STE (Fig. 1). First, 2D-STE was performed using a PST-30BT with 2–4.8 MHz phased-array transducer (Toshiba Medical Systems) to obtain 2D data sets in each patient. Then, 3D-STE was performed using a PST-25SX with 2–4 MHz phased array matrix transducer (Toshiba Medical Systems). This matrix transducer, which was originally developed to assess LV volume and function can scan a user selected volume that can be adjusted from 15 × 15 to 110 × 110 degrees [5–8,11]. We applied this technique to assess LA volume and function. The volume data were stored in raw data format for further analysis. Each 3D data set of left atrium was displayed in multiple planes view including the apical 2- and 4-chamber views. The examiner then set several markers on the LA endocardium in the apical 4-viewing planes. The first marker was set at the edge of the septal mitral valve ring and then markers were placed in a counter-clockwise rotation around the LA to the lateral mitral valve ring in the 4-chamber viewing plane. The software then detected the LA endocardium and the examiner selected a default thickness for the LA myocardium (2–3 mm) to define the LA epicardium. After the endocardial and epicardial contours had been selected, the system performed the wall motion tracking analysis throughout the entire cardiac cycle. The selection of the LA shape is semi-automatic and the tracking process is automated. The examiner was able to adjust the results of the tracking process when needed. 3D-STE was performed on the complete LA myocardium using the 3D data set. Thousands of tracking points on the reconstructed surfaces of the LA endocardium and epicardium were tracked and time–LA volume curves were constructed from these results.

**Measurement of LA volume and function by 3D-CT**

CT imaging was performed with a 64-slice CT scanner (Aquilion TSX-101A 64 rows, Toshiba Medical Systems, Tokyo, Japan). Radiographic contrast (100 ml of iopamidol, iodine 370 mg/ml) was injected intravenously at a flow rate of 3–5 ml/s (0.07 ml/kg/s) when there was 50 HU in the descending aorta, followed by 20 ml of a saline bolus. Beta blockers were not used for the CT imaging. Image reconstruction was performed by a personal computer that was a part of the CT system, and LA volume was automatically calculated by computer software (Virtual Press, AZE, Tokyo, Japan), excluding the LA appendage and pulmonary vein as previously reported [2]. Maximum LA volume, pre-atrial contraction volume, and minimum LA volume were measured using retrospective gating at the end of T wave, at the onset of P wave, and at the onset of QRS wave in continuous electrocardiography monitoring during CT acquisition with a time resolution of 50 ms (20 phases/s), respectively (Fig. 2). The effective slice thickness was 0.5 mm and 128 slices were used for the measurement of LA volume.

**Reproducibility of LA volume and function by 3D-STE**

We determined the interobserver variability of maximum LA volume measured by STE in 30 patients with chest pain or discomfort. Thirty randomly selected recordings were measured by two observers using 3D-STE in a blinded manner. Likewise, we determined the intraobserver variability of maximum LA volume in the same 30 recordings that were measured twice by one observer at a 7-day interval using 3D-STE.

**Statistical analysis**

Data are expressed as the mean ± one standard deviation. Simple linear regression analyses were performed to determine the relationship between LA volume and function measured by 3D-CT and STE. The degrees of agreement between 3D-CT and STE in LA volume and function were assessed using Bland–Altman plots. All statistical analyses were performed using Stat View version 5.0 (SAS Institution Inc., Cary, NC, USA). A p-value < 0.05 was considered to be significant.

**Results**

**Reliability of 2D-STE and 3D-STE**

The patients’ clinical and echocardiographic characteristics are listed in Table 1. The LA phasic volume and function were easily and rapidly obtained from the time–LA volume curve in about 1 min (Fig. 1). There were strong correlations between LA phasic volume measured by 3D-CT and those measured by 3D-STE ($r = 0.98, p < 0.001$). There were strong correlations between LA

**Table 1**

Clinical and conventional echocardiographic parameters.

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<td>Age, years</td>
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<td>62.0 ± 11</td>
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<td>Men, n (%)</td>
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<td>Diabetes mellitus, n (%)</td>
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<td>Hypertension, n (%)</td>
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<td>BSA, m²</td>
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<td>Systolic BP, mmHg</td>
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<td>Diastolic BP, mmHg</td>
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<td>Heart rate, beat/min</td>
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<td>LV mass index, g/m²</td>
<td>40.4 ± 6.9</td>
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<td>LVEF, %</td>
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<td>LAD, mm</td>
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Data are presented as mean ± SD or as number (percentage). BSA, body surface area; BP, blood pressure; LV, left ventricular; LVEF, left ventricular ejection fraction; E′, the ratio of transmitral inflow velocity to mitral tissue velocity; LAD, left atrial diameter.
Fig. 3. Comparison of left atrial volume and function between three-dimensional computed tomography and three-dimensional speckle tracking echocardiography or two-dimensional speckle tracking echocardiography in the apical two- and four-chamber views. 3D-CT, three-dimensional computed tomography; 3D-STE, three-dimensional speckle tracking echocardiography; 2D-STE, two-dimensional speckle tracking echocardiography; LA, left atrial; LAV, left atrial volume; AC, atrial contraction; EF, emptying function; 2CV, two-chamber view; 4CV, four-chamber view.

Reproducibility of 3D-STE

The intraobserver correlation coefficient and variability in maximum LA volume assessed by 3D-STE were 0.99 and 1.4 ± 6.0%, respectively. The interobserver correlation coefficient and variability in maximum LA volume assessed by 3D-STE were 0.99 and 0.2 ± 4.5%, respectively.
Fig. 4. Bland–Altman analysis of left atrial volume and function between three-dimensional computed tomography and three-dimensional speckle tracking echocardiography or two-dimensional speckle tracking echocardiography in the apical two- and four-chamber views. 3D-CT, three-dimensional computed tomography; 3D-STE, three-dimensional speckle tracking echocardiography; 2D-STE, two-dimensional speckle tracking echocardiography; LA, left atrial; LAV, left atrial volume; AC, atrial contraction; EF, emptying function; 2CV, two-chamber view; 4CV, four-chamber view.
Discussion

The present study is the first study to assess LA structure and function using 3D-STE. We validated the accuracy of 3D-STE for the evaluation of LA volume and function by comparison with 3D-CT. This study demonstrated that 3D-STE had better accuracy than 2D-STE for the evaluation of LA volume and function.

LA volume and function evaluated by STE

Three-dimensional imaging represents one of the latest and most significant developments in the field of echocardiography, and this technique improves the accuracy of the echocardiographic evaluation of cardiac chamber volumes [11–17]. Owing to this development, there are several reports on the measurement of LA phasic volume and function using conventional 3D echocardiography as well as 2D-STE [2,3,18–21]. Rohner et al. demonstrated that LA volumes and LAEF, as assessed by conventional 3D echocardiography, correlated well with the CT measurements (r = 0.92 and r = 0.82, p < 0.001, respectively) [22]. Recently, Mochizuki et al. reported that LA strain and synchrony could be assessed using 3D-STE with excellent reproducibility and how 3D-STE parameters are modified by AF [23]. However, there has been no study validating accurate in the measurement of LA volume and function using 3D-STE. It is very important to accurately assess not only LA phasic volume but also LA phasic function, since LA enlargement and reduced LA function as assessed by echocardiography is a robust predictor of cardiovascular outcomes [1,2,24,25].

LA function consists of a reservoir function during LV systole, conduit function during early diastole, and booster pump function during late diastole [26]. These three functions can be assessed as LA total EF, LA passive EF, and LA active EF using STE in routine clinical practice. As LV filling pressure progressively increases with advancing diastolic dysfunction, the LA serves predominantly as a conduit [2,4]. Thus, it is important to evaluate LA phasic function in detail because LA phasic function is directly influenced by LV diastolic function. We compared the accuracy of the measurement of LA volume and function between 2D-STE and 3D-STE, with 3D-CT serving as a gold standard. The present study demonstrated that 3D-STE had a better agreement with 3D-CT than 2D-STE. In addition, this study demonstrated that LA phasic volume and function could be easily and rapidly assessed using 3D-STE in routine clinical practice.

In the present study, the maximum LA volume measured by 3D-STE was systematically smaller than that measured by CT by 2.04 ml/m² and produced bias between them. The volume surrounded by the mitral valve and mitral annular plane were included in the LA volume by the CT measurement, however, those were not included by the STE measurement. This might be the major reason of disagreements between the two methods.

Study limitations

There were several limitations in the present study. First, 3D-STE has shortcomings such as low temporal resolution and random noise that affect the ability to track speckles during the cardiac cycle [13]. Improvement of the temporal resolution of 3D-STE could improve the accuracy of the measurement. Second, the time resolution of 3D-CT was 50 ms (20 phases/s) in the present study. Therefore, time intervals of phases were approximately 17 phases/cardiac cycle when the heart rate was 70 beats/s. Lower time resolution results in smaller maximum volume and larger minimum volume than those measured with greater time resolution. To ensure accurate quantification of cardiac volumes, reconstruction at time intervals smaller than 5% of the RR-interval (>20 phases/cardiac cycle) was recommended [27]. Third, we evaluated only a small number of patients using 3D-STE and 3D-CT because patients who need to undergo 3D-CT were limited. Evaluation of LA volume and function using 3D-STE in a large number of patients will be required in the future, including a validation study comparing 3D-STE with magnetic resonance imaging.

Conclusions

LA phasic volume and function were easily and accurately assessed by time–LA volume curve constructed using 3D-STE. 3D-STE was more accurate than 2D-STE for the quantitative measurement of LA volume and function and is a promising method to evaluate LA structure and function.

Conflict of interest

None declared.

Acknowledgments

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References


