Comparison of Automatic Boundary Detection and Manual Tracing Technique in Echocardiographic Determination of Left Atrial Volume

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Previous reports have indicated that echocardiography with automatic boundary detection (ABD) is useful for the noninvasive estimation of left ventricular volume. However, few data exist regarding the measurement of left atrial (LA) volume, which also provides pivotal information in the clinical setting. Therefore, the feasibility of LA volume measurement by ABD in comparison with the manual tracing using modified Simpson's method (SM) was evaluated. Fifty-nine patients with coronary artery disease with sinus rhythm were examined. Using ABD, a region of interest was set around the LA border and mitral annulus from an apical four-chamber view. The maximal and minimal LA volume (Vmax and Vmin) were measured from the volume waveform. Using the SM, the maximal and minimal LA volume were measured by the manual tracing on frozen frames at the apical four-chamber view. The ABD displayed a curve of LA volume change that consisted of passive emptying, diastasis, and active emptying phases during the left ventricular diastolic period. Under these conditions, the Vmax and Vmin were 43.7±11.2 ml and 21.1±7.6 ml, respectively, yielding the volume change of 22.6±6.0 ml. By the SM, Vmax and Vmin were 43.1±9.9 ml (r=0.94, p<0.0001, y(ABD)=0.91x(SM)+3.6) and 22.0±9.0 ml (r=0.91, p<0.0001, y=0.94x+0.7), respectively, and the volume change was 22.8±6.1 ml (r=0.82, p<0.0001, y = 0.84x + 3.8). These results indicate that the ABD from the apical four-chamber approach could provide an accurate estimation of LA volume change, suggesting the potential value of this method in assessing LA function, although some technical difficulties need to be further overcome. (Jpn Circ J 1998; 62: 755–759)

Key Words: Automatic boundary detection; Diastolic function; Left atrial volume

Left atrial function is of great importance in the normal heart as well as in the diseased heart, and its significant contribution to ventricular filling has been already discussed.1–7 The left atrium (LA) serves not only as a reservoir for the collection and storage of blood during left ventricular systole but also as a contractile pump to augment late left ventricular filling.8 Thus the evaluation of LA function as well as left ventricular function in diseased hearts is very useful for clinical decision-making particularly in the presence of heart failure.

For the noninvasive assessment of LA function, echocardiography has been used to calculate the LA volume with a manual tracing procedure2–6. However, real-time determination of LA volume may be more useful in clinical settings. Although echocardiography with the automatic boundary detection (ABD) technique enables measurement of the blood area within a region of interest and provides a noninvasive and real-time continuous cyclic volume change of the left ventricle9–13 or LA14–17 few data exist regarding the accuracy of this technique for the determination of LA volume. Therefore, using ABD we attempted to validate the LA volume changes in comparison with the manual tracing method using the modified Simpson's method on frozen frames from an apical four-chamber view.

Methods

Study Patients

A total of 59 patients with coronary heart disease that had been documented by coronary angiography and left ventriculography entered the present study. These patients were selected from 89 patients according to the following criteria: (1) more than 75% of the LA cavity and wall were adequately visualized from the apical four-chamber view; (2) with the proper machine settings the LA volume curve by ABD was obtained; and (3) normal sinus rhythm was present.

There were 54 men and 5 women, mean age of 60±8 years (range, 37–77 years), including 30 patients with angina pectoris, 13 with recent myocardial infarction and 16 patients with old myocardial infarction. None had evidence of mitral stenosis. Based on color flow images, mild or moderate mitral regurgitation was present in 23 patients.

Echocardiographic Examination

We used an echocardiographic system (Sonos 2500, Hewlett-Packard) with an ultrasound transducer operating at 2.5 MHz. All subjects were studied in the left lateral recumbent position, and the patients were asked to avoid
deep inspiration or Valsalva's maneuver. From the apical four-chamber view, the LA was visualized as clearly as possible.

Echocardiographic Automatic Boundary Detection

After obtaining the optimal image of the LA from the apical four-chamber view where the largest LA area was visualized, the acoustic quantification system was activated. The lateral gain compensation was used for enhancing edge detection of the atrial septum and lateral LA wall. A careful adjustment of the time gain and lateral gain compensations were required to optimize the clear visualization of the tissue-blood boundary.18,19 Then, a region of interest was set along the atrial septum, the mitral annulus, the lateral LA wall, and across the posterior LA wall at end systole as described by Waggoner et al.14 Under these conditions, we could ensure that the LA contour was correctly tracked using visual assessment by turning the border key on and off during the study.

The LA volume was estimated by the built-in ABD software with the algorithm fundamentally based on the modified Simpson's method used in the manual tracing technique. The LA volume waveform versus time was displayed along with the ECG and the two-dimensional image. All studies were recorded on s-VHS videotape for subsequent review and analysis.

Waveform Analysis by ABD

The waveform derived by ABD showed 3 phases during left ventricular diastolic filling. These consisted of (1) the passive empty phase, which began with the opening of the mitral valve, from maximal LA volume (point A) to the beginning of atrial diastasis (point B), identifying the rapid decrease of LA volume; (2) the atrial diastasis phase, when the LA volume remained relatively constant from the beginning of horizontal volume curve to the onset of active atrial systole (point C); and (3) the active emptying phase, which began with the onset of atrial systole to the minimal LA volume at the end diastole of the left ventricle (point D) (Fig 1).

Because in the present ABD system the computer did not necessarily display the maximal and minimal volume in real-time, we sometimes used the caliber of the ABD system to measure the LA volume. The maximal (Vmax) and minimal LA volume (Vmin) were determined at point A and point D, respectively. The total LA volume change was defined as the difference between the Vmax and Vmin. The values obtained by the ABD were obtained by averaging 5 consecutive cycles.

LA Volume by Manual Tracing With Modified Simpson’s Method

With the same plane for measurement of LA volume by the ABD, the Vmax and Vmin were measured from the conventional two-dimensional echocardiographic images by manually tracing the LA edges (Fig 2). The measurements were based on the innermost bright edge convention that disregarded the orifice of the pulmonary veins and the LA appendage. When dropout of the atrial septum occurred, the outline was completed by a straight line between the adjacent borders, and a straight line connecting both sides of the mitral leaflet at the level of the mitral valve annulus was taken as the border of the LA outline. Then, the volume was calculated by modified Simpson's method with the formula20: \( \frac{1}{4} \times L \times (\frac{1}{2} D)^2 \) where D represented the LA diameter and L represented the LA length.

The Vmax was measured at the frame just before the mitral valve opening and the Vmin was measured at the frame just before mitral valve closure. Then the total LA volume change was calculated by subtracting the Vmin from the Vmax.

In order to minimize the bias in tracing the two-dimen-
sional images, manual tracing and ABD estimation were performed separately.

Interobserver and Intraobserver Variabilities
The LA volume by ABD from a randomly selected 10 patients was measured by 2 independent observers (G.C. Z. and T. T) and by one observer (G.C. Z.) at 2 separate times. These data were used in the assessment of inter- and intraobserver variabilities. The results were expressed as a linear regression between the 2 measurements and percent error that was derived as the absolute difference divided by the initial measurements.

Statistical Analysis
All data were expressed as mean±SD. The data obtained by ABD waveform were compared with those obtained from the manual tracing with modified Simpson's method. Statistical significance was considered to be p<0.05. A simple linear regression analysis was performed to determine the relationship of LA volumes by 2 different methods.

Results

Intraobserver and Interobserver Variabilities
As for intraobserver variability, the measured Vmax, Vmin and volume change by G.C. Z. were 40.2±10.9 ml, 19.6±7.2 ml and 20.6±5.6 ml, respectively, for the first time, and 40.3±11.5 ml, 19.2±7.8 ml and 21.0±4.2 ml, respectively, for the second time. Thus the mean intraobserver variability was 1.7±2.6% with a coefficient of 0.97.

As for interobserver variability, the measured Vmax, Vmin and volume change by G.C. Z. were 33.5±9.2 ml, 15.9±4.8 ml and 17.6±4.8 ml, respectively, and those by T. T were 35.1±10.0 ml, 14.9±7.2 ml and 20.1±5.2 ml, respectively. Thus the mean interobserver variability was 4.3±5.2% with a coefficient of 0.92.

LA Volume Determined by Echocardiography
The ABD displayed a curve of LA volume change that

Fig 2. Illustration of manual tracing of left atrial (LA) volume from apical four-chamber view based on single-plane modified Simpson's method. (Left) At the frame just before mitral opening, maximal LA volume was measured, and (Right) at the frame just before mitral closure, minimal LA volume was measured. D, dimension of LA; LV, left ventricle; RA, right atrium; RV, right ventricle.

Fig 3. Correlation between left atrial volume derived from automatic boundary detection (ABD) and manual tracing with modified Simpson's method (SM). The horizontal axes represent the volume determined by SM, and the vertical axes represent the volume determined by ABD.
consisted of passive emptying, diastasis, and active emptying phases during the left ventricular diastolic period. Under these conditions, the Vmax and Vmin were 43.7±11.2 ml and 21.1±7.6 ml, respectively, yielding the volume change of 22.6±6.0 ml.

By the SM, Vmax and Vmin were 43.1±9.9 ml (r=0.94, p<0.0001, y=-0.91x+3.6) and 22.0±9.0 ml (r=0.91, p<0.0001, y=-0.94x+0.7), respectively, and the volume change was 22.8±6.1 ml (r=0.82, p<0.0001, y=-0.84x+3.8). The long axis length of the LA was 48.4±5.2 mm (range, 39.0–58.6 mm), indicating that the size of the LA did not exceed 60 mm in length. There were good correlations between the values determined by the 2 different methods (Fig 3).

Discussion

Previous Studies

The LA chamber size and function are considered to be influenced by the left ventricular systolic and diastolic functions in the physiologic and pathologic states such as valvular heart disease, dilated cardiomyopathy, hypertensive heart disease and ischemic heart disease. However, it has been somewhat difficult to routinely determine the LA volume by angiography. As for the noninvasive method, the LA volume determination by the manual tracing of two-dimensional echocardiographic images is time-consuming. Therefore, a noninvasive and real-time method for the LA volume calculation would be appreciated.

The ABD of acoustic quantification technology enables measurement of the blood area within a region of interest providing noninvasive and real-time determination of LA volume changes. However, previous studies have largely focused on area comparison and did not have the volume comparison.

Noninvasive Determination of LA Volume

As observed previously, we also found that the curve of the LA volume change displayed by the ABD was similar to that derived from left atrioangiography which demonstrated the early passive emptying, diastasis, and late active emptying phases during left ventricular diastolic filling. The Vmax and Vmin LA volumes obtained by ABD correlated well with those derived from the manual tracing technique with modified Simpson’s method that has been already established as the noninvasive standard for LA measurement. The Vmax and Vmin LA volume obtained by both methods in our study were in agreement with the results reported by Gutman et al who had shown by echocardiography that the LA volume change during a cardiac cycle was 24 ml on average.

Clinical Implications and Limitations

One of the important clinical implications of the present method was that the assessment of left ventricular diastolic function is sometimes difficult to evaluate from the left ventricular inflow pattern alone. Denis et al preliminarily reported that the measurement of LA volume using the ABD method enabled the differentiation of normal and pseudonormal mitral flow velocity pattern in the clinical setting.

The main limitation of the present study was the usage of two-dimensional tracing of LA volumes as a gold standard, although previous studies indicated a good correlation between the LA volume measurements by manual tracing and by angiography. Indeed, systematic underestimation of LA volume was reported by Kircher et al who demonstrated that underestimation by approximately 23% could occur in the measurement of LA volume by two-dimensional echocardiography. In particular, in the presence of an asymmetrically enlarged LA, it may be difficult to include the giant left atrium in one single viewing plane.

Because the volume measurement by the present ABD system was designed for only single plane instead of biplane views, we only used the same single-plane LA image to compare results from the 2 different methods. Another limitation of using ABD in the assessment of LA volume seemed to be that ABD measurement of LA volume relies on optimal two-dimensional images of the LA borders. The quality of the ABD images somewhat depends on a user-defined ROI, and is sensitive to time-gain compensation and transmitting power.

In the present patient population, the maximal length of the LA long axis was within 60 mm, indicating that patients with enlarged LA had not been included. However, from the clinical point of view, it is necessary to examine the patients with enlarged LA. Further study will be necessary to define the feasibility of the method for the determination of the volume of a giant LA. In spite of the existence of some difficulties to be resolved, however, we would suggest the potential value of this method in assessing LA volume as well as LA function, under the condition with optimal two-dimensional images and appropriate equipment settings.

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