Real-time Determination of Left Ventricular Ejection Fraction by Automatic Boundary Detection in Patients with Dilated Cardiomyopathy: A Comparison with Radionuclide Ventriculography

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Echocardiographic automatic boundary detection (ABD) is a new on-line technique which automatically outlines the left ventricular endocardial border and instantly calculates the left ventricular area and volume from two dimensional echocardiographic images. To determine if left ventricular ejection fraction (LVEF) can be derived using the ABD method, 25 consecutive patients with dilated cardiomyopathy, aged 52.1±15.2 (range 14~75), underwent complete echocardiographic examination with both the ABD method and radionuclide ventriculography (RVG). End-diastolic and end-systolic left ventricular areas were obtained on-line from the apical four chamber view. Left ventricular length was also measured from an apical view. Left ventricular volumes and ejection fraction were calculated using the single plane area-length method. ABD measurements could be obtained in all patients. Linear regression analysis compared ejection fraction derived by ABD and RVG. The mean radionuclide LVEF was 20.9±6.8% and mean ABD-derived LVEF was 227±5.8%. Linear regression analysis revealed that the ABD-derived LVEF is closely correlated with the RVG-derived LVEF (r=0.87, p<0.001). In conclusion, ABD echocardiography is a new on-line technique which may be used to accurately calculate LVEF in patients with dilated cardiomyopathy.

Key Words: Left ventricular ejection fraction, automatic boundary detection, dilated cardiomyopathy

Dilated cardiomyopathy is a heart muscle disease of unknown cause in which one or both ventricles are dilated and poorly contracting. Various clinical, radiological, angiographic, hemodynamic, and histopathological variables have been suggested as predictors of outcome in dilated cardiomyopathy (Unverferth et al. 1984; Likoff et al. 1987; Keogh et al. 1990). Among those variables, left ventricular ejection fraction (LVEF) is one of the most important factor which influence the management and predict the prognosis in patients with dilated cardiomyopathy (Diaz et al. 1987; Keogh et al. 1988). Echocardiography has emerged as an useful non-invasive diagnostic modality to assess left ventricular systolic and diastolic functions. However, routine applica-
tion of these measurements has been limited by the need for off-line calibration, hand-drawn borders, and computation. Recently, an echocardiographic automatic boundary detection (ABD) system has been developed (Perez et al. 1992; Vandenberg et al. 1992). In detecting the tissue-blood interface, instantaneous quantification of cardiac chamber areas and function can be obtained. This method has been shown to be reproducible in the clinical assessment of cardiac function at bedside (Waggoner et al. 1994; Sun et al. 1995).

However, whether the assessment of ventricular volumes and ejection fraction with ABD is applicable to patients with dilated cardiomyopathy has not been demonstrated previously.

The objectives of this study were ① to assess the feasibility of real-time ABD for visualization of left ventricular endocardial borders in patients with dilated cardiomyopathy and ② to compare radionuclide ventriculography (RVG)-derived LVEF with ABD-derived LVEF in patients with dilated cardiomyopathy.

**MATERIALS AND METHODS**

**Study Patients**

Complete echocardiographic studies were performed on 25 consecutive patients of dilated cardiomyopathy with normal sinus rhythm. Thirteen were men and 12 were women. The mean age was 52.1 ± 15.2 (range 14 to 75 years). The diagnosis of dilated cardiomyopathy was based on electrocardiography, coronary arteriography and echocardiographic findings (no demonstrable pathologic Q wave, no significant coronary arterial luminal narrowing and no scarring change of left ventricular myocardium). Eight (32%) out of 25 patients had moderate to severe degree of mitral regurgitation. Nine (36%) out of 25 patients were New York Heart Association functional class 3 and 4.

**Echocardiographic data acquisition**

A meticulous examination was performed to optimize endocardial definition. All patients were studied with a commercially available ultrasound imaging system with Doppler capability (Hewlett-Packard Sonos 1500; Hewlett-Packard Co., Palo Alto, Calif, USA) with a 2.5 MHz transducer. Two-dimensional echocardiographic studies were performed from standard transducer positions. The apical four chamber view was obtained by placing the transducer at or lateral to the point of maximal impulse then adjusted until the optimal endocardial surfaces were obtained. Off-line measurements of left ventricular end-diastolic and end-systolic dimensions were performed from M-mode tracing of parasternal short axis view at the papillary muscle level. LVEF was also calculated from M-mode echocardiography.

**Radionuclide ventriculography**

All of the patients underwent ECG-gated RVG to assess the regional myocardial contractility and to measure LVEF. The thirty minutes after an injection of 1 mg of pyrophosphate, 20 mci (740 MBq) of Tc-99m-pertechnete was given to the antecubital vein. Anterior, left anterior oblique (LAO) and lateral views at preset 1000 K counts were obtained. R-R interval was divided into 24 frames. The LVEF was measured manually by drawing a ROI over the left ventricle on LAO view. The regional wall motion was assessed visually.

**Automatic boundary detection**

The integrated backscatter imaging system employs a relatively long integration time (3.2 usec) over which each radiofrequency A-line

<table>
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<th>Table 1. Clinical characteristics of study patients</th>
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<tr>
<td>Age(years)</td>
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<tr>
<td>Sex(M/F)</td>
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<tr>
<td>NYHA class(2/3/4)</td>
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<tr>
<td>Duration of symptom(months)</td>
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<td>Heart rate(beats/min)</td>
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<td>MR(grade 0/1/2/3)</td>
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Data presented are mean value±SD or number of patients. M: male, F: female, MR: mitral regurgitation, NYHA: New York Heart Association.
is analyzed. Approximately 100 data points of backscatter are collected along each line and the information is sent to the scan converter for on-line construction of the image in real time. The resulting two-dimensional integrated backscatter image data were considerably smoothed and averaged, resulting in a marked reduction of speckle noise in the image (Skorton et al. 1990). Discrimination of the endocardial-blood interfaces or boundaries was, therefore, facilitated, allowing automatic detection and tracking of these boundaries in real time (Fig. 1)(Perez et al. 1992). Lateral gain control allowed selective amplification of the sides compared with the middle of the imaging sector. After tracing a region of interest drawn around the blood pool cavity in the apical four chamber view, left ventricular end-diastolic volume, end-systolic volume, and ejection fraction were obtained with automatic boundary detection and with on-line volume waveforms calculated from a single-plane area-length method (volume=$8A^2/3\times L$). Cardiac output by ABD was calculated from heart rate multiplied by stroke volume.

**Doppler echocardiography**

For Doppler calculation of cardiac output, the pulsed Doppler sample volumes were placed on the ventricular side (approximately 1 cm below the aortic valve) of the aortic valve. Time-velocity integrals of the flow were obtained. The aortic annulus diameter was measured from parasternal long axis view (distance between the hinge points of the aortic leaflets at maximum valve opening). Stroke volume was calculated by multiplying time velocity integral (TVI) of aortic flow by the cross sectional area of the left ventricular outflow tract. Cardiac output was obtained by multiplying stroke volume by heart rate (Zoghbi and Quinones, 1986).

**Statistics**

All data were expressed as mean±standard deviation. ABD-derived LVEF was compared with RVG-derived LVEF. Cardiac output by ABD was compared with Doppler derived car-
Results

The optimal image acquisitions for ABD were possible in all patients. The clinical characteristics and results of echocardiographic assessment were summarized in Table 1, and Table 2. The mean LVEF from RVG was 20.9 ± 6.8%.

Comparison of left ventricular ejection fraction derived from automatic boundary detection and radionuclide ventriculography

ABD-derived LVEF correlated well with RVG-derived LVEF (r = 0.865, p < 0.001) (Fig. 2). There was also good correlation between ABD-derived LVEF and LVEF obtained by off-line analysis of M-mode echocardiography (r = 0.659, p < 0.001) (Fig. 3).

Table 2. Results of echocardiographic assessment

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<tr>
<td>Left ventricular</td>
<td>72.8 ± 7.5</td>
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<tr>
<td>end-diastolic dimension(mm)</td>
<td>65.0 ± 7.5</td>
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<tr>
<td>Left ventricular end-systolic dimension(mm)</td>
<td>10.7 ± 3.9</td>
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<tr>
<td>Fractional shortening(%)</td>
<td>22.1 ± 6.8</td>
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<tr>
<td>Left ventricular ejection fraction by M-mode echo(%)</td>
<td>0.75 ± 0.28</td>
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<tr>
<td>E(m/sec)</td>
<td>0.62 ± 0.30</td>
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<tr>
<td>A(m/sec)</td>
<td>175.5 ± 98.6</td>
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<tr>
<td>Deceleration time of E wave(msec)</td>
<td>110.0 ± 49.8</td>
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<tr>
<td>Isovolumic relaxation time(msec)</td>
<td>32.5 ± 12.5</td>
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<tr>
<td>Stroke volume by Doppler(ml)</td>
<td>220.8 ± 7.10</td>
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<tr>
<td>Left ventricular end-diastolic volume by ABD(ml)</td>
<td>170.6 ± 56.0</td>
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<tr>
<td>Left ventricular end-systolic volume by ABD(ml)</td>
<td>22.7 ± 5.8</td>
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<tr>
<td>Fraction by ABD(%)</td>
<td>50.2 ± 20.3</td>
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Data presented are mean value ± SD. ABD: automatic boundary detection, E: peak velocity of diastolic early filling, A: peak velocity of late diastolic flow during atrial contraction.
Real-time Determination of Ejection Fraction by Automatic Boundary Detection

![Graph showing comparison of cardiac output (CO) measured by both the on-line automatic boundary detection (ABD) and Doppler echocardiography.](image)

**Fig. 5. Comparison of cardiac output (CO) measured by both the on-line automatic boundary detection (ABD) and Doppler echocardiography.**

**Accuracy of automatic boundary detection-derived stroke volume and cardiac output**

ABD-derived stroke volume well-correlated with that from the aortic Doppler echocardiography \(r = 0.703, p < 0.001\) (Fig. 4). There was also good correlation between ABD-derived cardiac output and aortic Doppler-derived cardiac output \(r = 0.641, p = 0.001\) (Fig. 5).

**DISCUSSION**

Calculation of LVEF has important diagnostic, prognostic, and therapeutic implications in patients with heart disease. To calculate LVEF, a rapid, accurate, reproducible, and noninvasive method of calculation is desirable (Becker et al. 1983; Pfeffer et al. 1992). LVEF obtained from gated blood pool scanning have proved to be accurate when compared to cine angiography and are highly reproducible despite potential technical errors (Johnson and Tauxe, 1994). LVEF from cineangiography or cine MRI are calculated from volumes derived from either the area-length method or Simpson's rule, whereas LVEF from gated blood pool scans is measured from changes in counts and therefore it is geometry independent. However, because it is rather expensive and necessitates the exposure of the patient to radiation, it is a suboptimal test when serial assessment are required. Moreover, in patients with critically ill and equipped with many life-supporting devices, it is not always possible to move the patient to the radionuclide unit.

Echocardiography has emerged as an useful non-invasive diagnostic modality to assess left ventricular systolic and diastolic functions and has some advantages in such clinical settings due to portability with real time imaging and availability of repetitive examination without any harmful effects. However, routine application of the evaluation of ventricular dimensions and the assessment of the left ventricular systolic function has been limited by the need for off-line calibration and video image analysis, hand-drawn borders, and computation. Recently, an echocardiographic ABD system has developed by several investigators reported the feasibility of this new system. Perez et al. (1992) demonstrated on-line assessment of ventricular function by ABD in 54 patients and 12 normal controls and reported more than 70% success rate with excellent correlation with manually drawn results. However, the usefulness and accuracy of this method in patients with dilated cardiomyopathy have not been demonstrated previously. In this report, we demonstrated a high rate of image acquisition and good correlation with other conventional methods. Sun et al. (1995) have evaluated the validity of automatic echocardiographic quantification of LVEF in 50 patients in the intensive care unit and reported that echocardiography with ABD method yielded rapid and accurate results compared with thermodilution, two dimensional images and Doppler measurements.

Evaluation of left ventricular contractility in patients with congestive heart failure is an important part of clinical assessment. Changes in loading conditions, ventricular shape and valvular function limit the efficacy of commonly used ejection phase indices of function. Left ventricular end-systolic pressure-volume relations has been investigated to improve characterization of left ventricular contractility (Suga et al. 1973; Suga and Sagawa. 1974; Grossman et al. 1977; Sagawa. 1978; Kass et al. 1986).
A major limitation in determining these relations has been the acquisition of on-line volume data in vivo. Previous radionuclide technique or standard echocardiography to measure left ventricular volume have relied on tedious frame by frame analysis, often requiring manual tracing of the endocardial border (Grossman et al. 1977; Magorien et al. 1983; Kronenberg et al. 1985). Sonomicrometry and conductance catheter techniques have provided continuous estimates of volume throughout the cardiac cycle (McKay et al. 1984; Kass et al. 1986). However, these invasive methods have some inherent limitations in many clinical and investigational settings. Echocardiographic ABD is a feasible non-invasive technique that is capable of continuously measuring left ventricular area and volume on-line. Gercsan et al. (1994) demonstrated the usefulness of on-line pressure-area relations using ABD method in the open chest canine model.

Although the identification of endocardium and epicardium is a well-recognized difficulty in the quantitative analysis of two-dimensional echocardiographic images, we obtained a satisfactory result with ABD in all studied patients probably due to good ultrasound windows in patients with dilated cardiomyopathy. Further research regarding pressure-volume relation of left ventricle using on-line determination of left ventricular volume with ABD in patients with dilated cardiomyopathy is warranted.

REFERENCES


Keogh AM, Baron DW, Hickie JB: Prognostic guides in patients with idiopathic or ischemic dilated cardiomyopathy assessed for cardiac transplantation. Am J Cardiol 65: 903-905, 1990


Pfeffer MA, Braunwald E, Mojte LA, Basta L, Brown EJ, Cuddy TE, Davis BR, Geltman EM,


