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

Jong-Won Ha, Namsik Chung, Kyung-Hoon Choe*
June Kwan**, Se-Joong Rim, Yangsoo Jang, Ji-Young Kim
Eun-Kyung Oh, Young-Joon Lee, Won-Heum Shim, Seung-Yun Cho,
and Sung Soon Kim

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 22.7±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-

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Cardiology Division, Cardiovascular Center, Yonsei University College of Medicine, Seoul, Korea
*Cardiology Division, Wonju College of Medicine, Yonsei University, Wonju , Korea
**Division of Cardiology, Inha University, Incheon, Korea
Address reprint request to Dr J.W. Ha, Cardiology Division, Yonsei Cardiovascular Center, Yonsei University College of Medicine, C.P.O. Box 8044, Seoul 120-752, Korea
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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-pertechnate 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 1. Clinical characteristics of study patients

Age(years)	52.1±15.2
Sex(M/F)	13/12
NYHA class(2/3/4)	17/6/3
Duration of symptom(months)	17.2±27.5
Heart rate(beats/min)	81.3±15.1
MR(grade 0/1/2/3)	4/11/3/5

Data presented are mean value±SD or number of patients. M: male, F: female, MR: mitral regurgitation, NYHA: New York Heart Association

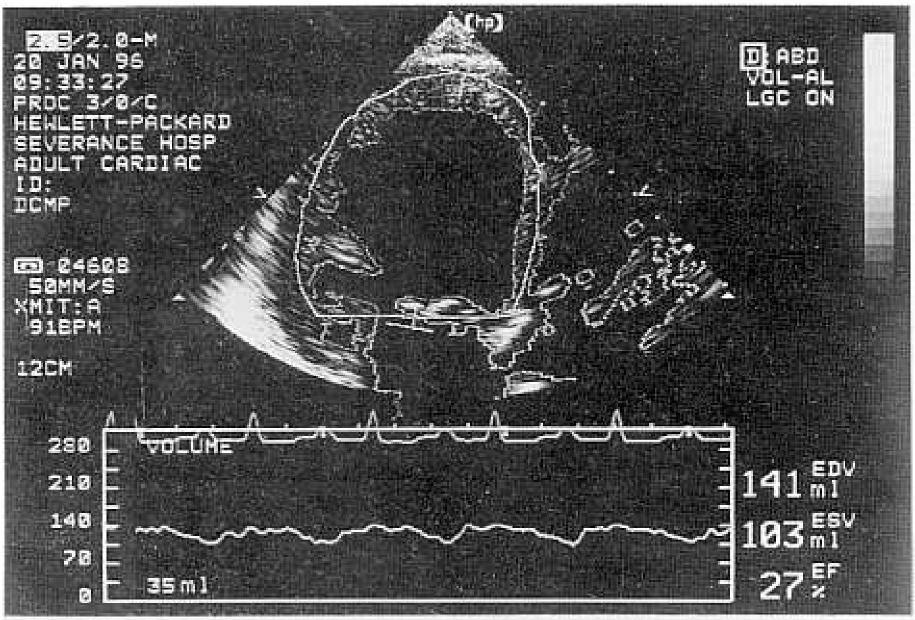

Fig. 1. *Automatic boundary detection image of apical four chamber view with the region of interest drawn around the left ventricular cavity. The graphs on the bottom demonstrate the instantaneously measured and displayed cavity volume and ejection fraction computed beat by beat.*

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 cardiac output. Measurements averaged from three cardiac cycles were analyzed by linear regression analysis.

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

Left ventricular end-diastolic dimension(mm)	72.8 ± 7.5
Left ventricular end-systolic dimension(mm)	65.0 ± 7.5
Fractional shortening(%)	10.7 ± 3.9
Left ventricular ejection fraction by M-mode echo(%)	22.1 ± 6.8
E(m/sec)	0.75±0.28
A(m/sec)	0.62±0.30
Deceleration time of E wave(msec)	175.5±98.6
Isovolumic relaxation time(msec)	110.0±40.8
Stroke volume by Doppler(ml)	32.5±12.5
Left ventricular end-diastolic volume by ABD(ml)	220.8±7.10
Left ventricular end-systolic volume by ABD(ml)	170.6±56.0
Left ventricular ejection fraction by ABD(%)	22.7 ± 5.8
Stroke volume by ABD(ml)	50.2 ±20.3

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

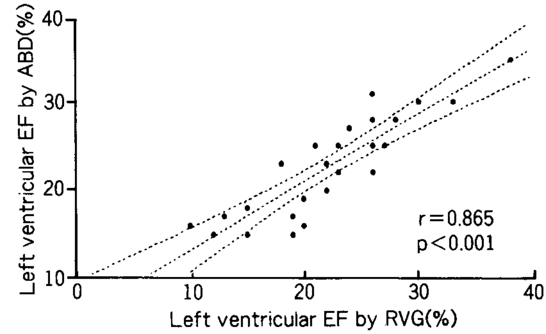

Fig. 2. *Comparison of left ventricular ejection fraction (EF) measured by both the on-line automatic boundary detection (ABD) and radionuclide ventriculography (RVG).*

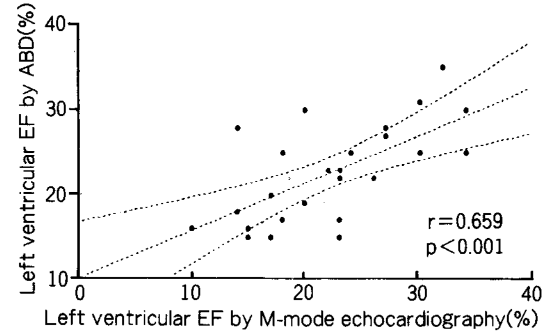

Fig. 3. *Comparion of left ventricular ejection fraction (EF) measured by both the on-line automatic boundary detection (ABD) and M-mode echocardiography.*

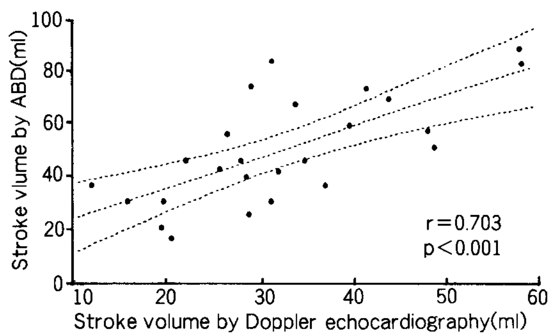

Fig. 4. *Comparison of stroke volume measured by both the on-line automatic boundary detection (ABD) and doppler echocardiography.*

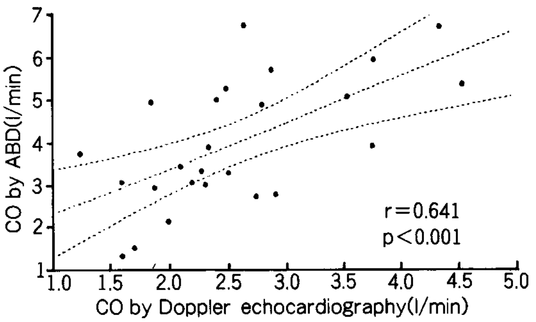

Fig. 5. Comparison of cardiac output (CO) measured by both the on-line automatic boundary detection (ABD) and Doppler echocardiography.

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 and 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. Gorcsan *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

Becker LC, Silverman KS, Bulkley BH, Kallman CH, Mellits ED, Weisfeldt M: Comparison of early thallium-201 scintigraphy and gated blood pool imaging for predicting mortality in patients with acute myocardial infarction. *Circulation 67: 1272-1282, 1983*

Diaz RA, Obasohan A, Oakley CM: Prediction of outcome in dilated cardiomyopathy. *Br Heart J 58: 393-399, 1987*

Gorcsan J III, Romand JA, Mandarino WA, Deneault LG, Pinsky MR: Assessment of left ventricular performance by on-line pressure-area relations using echocardiographic automated border detection. *J Am Coll Cardiol 23: 242-252, 1994*

Grossman W, Braunwald E, Mann T, McLaurin LP, Green LH: Contractile state of the left ventricle in man as evaluated from end-systolic pressure-volume relations. *Circulation 56: 845-852, 1977*

Johnson LJ, Tauxe EL: Radionuclide assessment of ventricular function. *Curr Prob Cardiol 10: 589-636, 1994*

Kass DA, Yamazaki T, Burkhoff D, Maughan WL, Sagawa K: Determination of left ventricular end-systolic pressure-volume relationships by the conductance(volume) catheter technique. *Circulation 3: 586-595, 1986*

Keogh AM, Baron DW, Hickie JB: Prognostic guides in patients with idiopathic or ischemic dilated cardiomyopathy assessed for cardiac transplantation. *Am J Cardiol 65: 903-908, 1990*

Keogh AM, Freund J, Baron DW, Hickie JB: Timing of cardiac transplantation in idiopathic dilated cardiomyopathy. *Am J Cardiol 61: 418-422, 1988*

Kronenberg MW, Parrish MD, Jenkins DW, Sandler MP, Friesinger GC, James J, Wolfe OH: Accuracy of radionuclide ventriculography and end-systolic pressure-volume relations. *J Am Coll Cardiol 6:1064-1072, 1985*

Likoff ML, Chandler SL, Kay HR: Clinical determinants of mortality in chronic congestive heart failure secondary to idiopathic dilated or to ischemic cardiomyopathy. *Am J Cardiol 59: 634-638, 1987*

Magorien DJ, Shaffer P, Bush CA, Magorien RD, Kolibash AJ, Leier CV, Bashore TM: Assessment of left ventricular pressure-volume relations using gated radionuclide angiography, echocardiography and micromanometer pressure recordings. *Circulation 67: 844-853, 1983*

McKay RG, Spears JR, Aroesty JM, Baim DS, Royal HD, Heller GV, Lincoln W, Salo RW, Braunwald E, Grossman W: Instantaneous measurements of left and right ventricular stroke volume and pressure-volume relationships with an inpedance catheter. *Circulation 69: 703-710, 1984*

Perez JE, Waggoner AD, Barzilai B, Melton Jr HE, Miller JG, Sobel BE: On-line assessment of ventricular function by automatic boundary detection and ultrasonic backscatter imaging. *J Am Coll Cardiol 19: 313-320, 1992*

Pfeffer MA, Braunwald E, Moye LA, Basta L, Brown EJ, Cuddy TE, Davis BR, Geltman EM, Goldman S, Flaker GC, Klein M, Lamas GA, Packer M, Rouleau JL, Rutherford J, Wertheimer JH, Hawkins CM: Effect of captopril on mortality and morbidity in patients with left ventricular dysfunction after myocardial infarction. *N Engl J Med 327: 669-677, 1992*

Sagawa K: The ventricular pressure-volume diagram revisited. *Circ Res 43: 677-687, 1978*

Skorton DJ, Miller JG, Wickline SA: Ultrasonic characterization of cardiovascular tissue. In Marcus M, Schelbert HR, Skorton DJ, Wolff G, eds. Cardiac imaging: Principles and practice. *Philadelphia WB Saunders, 1999, 538-556*

Suga H, Sagawa K: Instantaneous pressure-volume relationships and their ratio in the excised, supported canine left ventricle. *Circ Res 35: 117-126, 1974*

Suga H, Sagawa K, Shoukas AA: Load independence of the instantaneous pressure-volume ratio of the canine left ventricle and effects of epinephrine and heart rate on the ratio. *Circ Res 32: 314-322, 1973*

Sun JP, Stewart WJ, Yang XS, Lee KS, Sheldon WS, Thomas JD: Automated echocardiographic quantitation of left ventricular volumes and ejection fraction: Validation in the intensive care setting. *J Am Soc Echocardiogr 8: 29-36, 1995*

Unverferth DV, Magorien RD, Moeschberger ML, Baker PB, Fetters JK, Leier CV: Factors influencing the one-year mortality of dilated cardiomyopathy. *Am J Cardiol 54: 147-152, 1984*

Vandenberg BF, Rath L, Shoup TA,Kerber RE, Collins SM, Skorton DJ: Cyclic variation of ultrasound backscatter in normal myocardium: Clinical studies with a real-time backscatter imaging system. *J Am Soc Echocardiogr 4: 10-18, 1991*

Vandenberg BF, Rath LS, Stuhlmuller P, Melton Jr HE, Skorton DJ: Estimation of left ventricular cavity area with an on-line, semiautomated echocardiographic edge detection system. *Circulation 86: 159-166, 1992*

Waggoner AD, Miller JG, Perez JE: Two-dimensional echocardiographic automatic boundary detection for evaluation of left ventricular function in unselected adult patients. *J Am Soc Echocardiogr 7: 459-464, 1994*

Zoghbi WA, Quinones MA: Determination of cardiac output by Doppler echocardiography: a critical appraisal. *Herz 11: 258, 1986*