CONTINUOUS-WAVE DOPPLER ECHOCARDIOGRAPHY FOR EVALUATING LEFT VENTRICULAR PERFORMANCE

— Clinical Significance of a New Systolic Time Interval —

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Left ventricular performance was evaluated in 51 patients with acute myocardial infarction and angina pectoris using parameters derived from the flow velocity waveform at the ascending aorta. Flow velocity waveforms were obtained from the suprasternal notch by continuous-wave Doppler echocardiography and were recorded on a line-scan recorder at a paper speed of 100 mm/sec with lead II ECG. The peak flow velocity and the systolic time interval from the beginning of ECG Q wave to the peak flow velocity (Q-V peak interval) were measured. Relationships were investigated between these parameters and the left ventricular ejection fraction (LVEF) obtained from multigated equilibrium blood pool imaging with ^{99m}Tc -pertechnetate. The peak flow velocity did not correlate with LVEF ($r=0.27$). However, a highly significant negative correlation was observed between the systolic time interval Q-V peak and LVEF ($r=-0.84$, $p<0.001$). The regression equation was $\text{LVEF} = -0.46 \times (\text{Q-V peak}) + 142$. We conclude that left ventricular performance can be evaluated in patients with coronary artery disease at the bedside using the Q-V peak interval measured from simultaneous recording of the velocity waveform at the ascending aorta and the ECG.

M-MODE and two-dimensional echocardiography are widely used for evaluating left ventricular performance in patients with heart disease. However, these methods are not so useful for quantitating left ventricular performance in patients with coronary artery disease since their left ventricles often show abnormal wall motion. Previously, several investigators evaluated left ventricular performance in such patients using peak velocity and maximum

acceleration of aortic blood flow at the ascending aorta obtained by Doppler echocardiography^{1,2}. In this study we attempted to predict the left ventricular ejection fraction (LVEF) in coronary artery disease patients using a new systolic time interval obtained by continuous-wave Doppler echocardiography and ECG, evaluating whether one can predict the LVEF using the peak flow velocity at the ascending aorta.

Key words:

Doppler echocardiography
Systolic time interval
Left ventricular performance
Coronary artery disease

SUBJECTS AND METHODS

We studied 53 patients who were under-

(Received March 14, 1990; accepted September 10, 1990)

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Fig. 1. Simultaneous recording of continuous-wave Doppler echocardiography and lead II electrocardiogram. Peak flow velocity of the ascending aorta and the systolic time interval, the Q-V peak were measured.
CW=continuous-wave Doppler echocardiography

going radionuclide cardiography for the evaluation of left ventricular performance. No patient had valvular heart disease noted on two-dimensional and Doppler echocardiography, left bundle branch block or atrial fibrillation. Two patients were excluded from the study because of the lack of good quality Doppler echocardiographic recordings. Thus the final population consisted of 51 patients, 44 men and 7 women aged 38–82 years. Their heart rates ranged from 50 beats/min to 98 beats/min. Thirty-four suffered from acute myocardial infarction (AMI) and 17 from angina pectoris. Examinations were performed 2 weeks after hospital admission in the patients with AMI. The subjects with angina pectoris were studied as outpatients. Patients with AMI received no catecholamines and β -blockers during the examination periods. In the patients with angina pectoris, β -blockers were discontinued at least 3 days before the examination. Informed consent was obtained from all patients before the study.

Flow velocity waveforms at the ascending aorta were obtained with the patient supine using continuous-wave Doppler echocar-

diography (Toshiba SSH-60A) with a 2.5 MHz pencil-type transducer from the supra-sternal notch. The waveforms were recorded on a line-scan recorder at a paper speed of 100 mm/sec with lead II ECG. The peak flow velocity, the systolic time interval from the beginning of ECG Q wave to the peak flow velocity (Q-V peak interval), and the R-R interval were measured for 5 successive cardiac cycles by one cardiologist who did not know the patient's history or the results of other examinations (Fig. 1). The Q-V peak/ $\sqrt{RR}$ of each patient was calculated to correct for the effect of heart rate. Mean values of each parameter measured from 5 cardiac cycles were used in the analyses. We investigated the relationships between these parameters and the LVEF obtained by multigated radionuclide equilibrium blood pool imaging.³ Radionuclide cardiography was performed using the Hitachi Gamma View F connected to the data analyzer Hitachi HARP-RP-100. In the radionuclide studies we used red blood cells labeled with stannous pyrophosphate and 740–1100 MBq ^{99m}Tc -pertechnetate. The left anterior oblique view (30–45 degrees) was used in all

Fig.2. Correlation between peak flow velocity at the ascending aorta and LVEF. Peak flow velocity did not correlate with LVEF. LVEF=left ventricular ejection fraction

Fig.3. Correlation between the Q-V peak interval and LVEF. A highly significant negative correlation was observed between the Q-V peak interval and LVEF.

Fig.4. Correlation between the Q-V peak/ $\sqrt{RR}$ and LVEF. The Q-V peak/ $\sqrt{RR}$ which was considered the effect of heart rate on Q-V peak interval showed the correlation coefficient to be as high as that between the Q-V peak interval and LVEF.

Fig.5. Percent difference between the measurements of the Q-V peak interval by one observer on two occasions in each of 51 patients. The mean percent difference was 2.7%.

Fig.6. Percent difference between two observers for individual measurements of the Q-V peak interval in 51 patients. The mean percent difference was 3.7%.

subjects to separate the left ventricle from the other cardiac chambers. LVEF was calculated according to the general formula: $LVEF = (EDC - ESC) / EDC \times 100$, where EDC=left ventricular counts at end-diastole and ESC=left ventricular counts at end-systole. Both the EDC and ESC were background-corrected. The end-diastolic and end-systolic regions of interest were visually inspected and manually enclosed by a light pen on the monitor screen by a cardiologist who did not know the results of Doppler echocardiographic examination in these patients. Within the regions of interest, the outline of the ventricle was defined automatically. Continuous-wave Doppler echocardiography and radionuclide cardiography were performed simultaneous-

ly.

Statistical analyses were carried out by a third cardiologist who was not aware of the examination results. Finally, to determine intraobserver variability, the Q-V peak intervals were measured by one observer on two occasions in each of 51 subjects. To determine interobserver variability, a second observer independently measured the Q-V peak intervals in the same 51 patients. The variability was expressed as the per cent difference for each measurement and was determined as the difference between the two observations divided by the mean value of the two observations.

Statistical analysis

Correlations between the Q-V peak interval and LVEF, peak flow velocity of the ascending aorta and LVEF, Q-V peak/ $\sqrt{RR}$ and LVEF were evaluated using linear regression analysis calculated by the least-squares method. Probability levels less than 0.05 were considered significant.

RESULTS

The relationship between the peak flow velocity and LVEF is shown in Fig. 2. Peak flow velocity which ranged from 40 cm/sec to 115 cm/sec did not show a significant correlation with LVEF ($r=0.27$). Fig. 3 shows the relationship between the Q-V peak interval and LVEF. The Q-V peak intervals were distributed from 140 msec to 250 msec. A highly significant negative correlation was observed between the Q-V peak interval and LVEF ($r=-0.84$, $p<0.001$). The regression equation was $LVEF = -0.46 \times (Q-V \text{ peak}) + 142$. To correct for the effect of heart rate, Q-V peak intervals were divided by the square root of the R-R interval. The correlation between the Q-V peak/ $\sqrt{RR}$ and LVEF was $r=-0.85$, highly significant ($p<0.001$), and as high as the correlation between the Q-V peak interval and LVEF (Fig. 4). Intraobserver variability in the measurement of the Q-V peak interval was 2.7% (Fig. 5). The interobserver variability was 3.7% (Fig. 6).

DISCUSSION

Peak flow velocity of the ascending aorta

and the systolic time interval, the Q-V peak can be easily measured from the simultaneous recording of the flow velocity waveform of the ascending aorta and the ECG. We investigated the relationships between these parameters and the LVEF obtained by radionuclide cardiography. Peak flow velocity of the ascending aorta did not correlate with LVEF. Several investigators have reported that the peak flow velocity of the ascending aorta expresses left ventricular performance^{1,2,4-8}. Bennett et al⁷ showed that the peak flow velocity of the ascending aorta, obtained with catheter-tip electromagnetic flowmeter, had a good correlation with LVEF. Sabbah et al¹ also showed that the peak flow velocity of the ascending aorta derived from continuous-wave Doppler echocardiography well correlated with LVEF. However, Hatle et al⁹ reported that the peak flow velocity of the ascending aorta obtained by pulsed Doppler echocardiography did not reflect left ventricular performance in a patient with cardiomyopathy. Moreover, there are reports that the peak flow velocity of the ascending aorta is diminished among the elderly without heart disease¹⁰⁻¹². Left ventricular performance may be impaired with age¹². In addition, an increased tortuosity of the aorta and dilatation of the aortic root affect the Doppler intercept angle^{13,14} making it difficult to measure the true ejection flow velocity of the ascending aorta. We consider it inconvenient to correct the misalignment between the ultrasound beam and the blood flow direction on the two-dimensional echocardiogram at the patient's bedside. The lack of correlation between the peak flow velocity of the ascending aorta and LVEF observed in this study can best be explained by the wide age range (38-82 years) of the patients evaluated.

The profile of blood flow velocity in the ascending aorta has been reported to be flat¹⁵. We can therefore accurately measure the interval between the ECG Q wave to the peak flow velocity of the ascending aorta in those patients in whom we cannot align the ultrasound beam to the blood flow direction in the ascending aorta. The Q-V peak interval is composed of the left ventricular pre-ejection period (PEP) and the acceleration phase of the aortic blood flow in systole. It

has been reported that the PEP lengthens and the maximum acceleration rate of aortic ejection flow falls with impaired left ventricular performance^{1,2,4-8,16-18}. From the latter finding the acceleration time of aortic ejection flow is considered to lengthen with the deterioration in left ventricular performance. It is difficult to determine precisely the beginning of ejection on the waveform of continuous-wave Doppler recordings. Therefore, we attempted to evaluate left ventricular performance using the Q-V peak interval composed of PEP and the acceleration time of aortic ejection flow. We found that the Q-V peak interval correlated very well with LVEF, as did the Q-V peak/ $\sqrt{RR}$, with the correlation coefficients being similar. We consider that the heart rate did not affect the Q-V peak interval because no patient in the study had marked tachycardia or bradycardia.

To use this interval as a reliable index of left ventricular performance, little intra- and interobserver variability would be required. We found that intra- and interobserver variability was low, 2.7% and 3.7%, respectively, making the Q-V peak interval a reliable index of left ventricular performance.

We questioned which systolic time interval would be superior for evaluating LVEF, considering the Q-V peak interval and two established systolic time intervals: the left ventricular pre-ejection period (PEP), and the left ventricular pre-ejection period/left ventricular ejection time (PEP/LVET). In evaluating the latter two indices, Garrard and colleagues¹⁸ found a high correlation between the PEP/LVET and LVEF obtained by cine-ventriculography in patients with various heart diseases. In their study, however, the correlation between the PEP/LVET and LVEF was relatively low in coronary artery disease. In our patients with coronary artery disease, we observed a close correlation between the Q-V peak interval and the LVEF, although the method of obtaining LVEF differed in Garrard's study and ours. In a previous investigation, we compared the correlations between three systolic time intervals and LVEF from cine-ventriculography in patients with coronary artery disease, measuring systolic time intervals from the flow velocity waveforms obtained with a catheter-tip electromagnetic

flowmeter inserted in the ascending aorta. In that study, the Q-V peak interval showed a better correlation with the LVEF than the other two parameters!⁹

We conclude that the systolic time interval Q-V peak is useful for evaluating LVEF in patients with coronary artery disease. This parameter can be used conveniently and noninvasively at the bedside.

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