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Index of Myocardial Performance Using Doppler-Derived Parameters in the Evaluation of Left Ventricular Function in Patients with Essential Hypertension

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We analyzed Doppler echocardiographic data in 120 subjects with normal sinus rhythm; normals (NL, n=60, ages 54.1±15.1) and essential hypertensive patients (HT, n=60, ages 57.3±10.2). The IMP was calculated as follows: IMP=(ICT+IRT)/ET, ICT; isovolumic contraction time, IRT; isovolumic relaxation time, ET; ejection time. There were no significant differences in ejection fraction (EF), stroke volume index (SVI), cardiac index (CI), ET and ICT between NL and HT. There were, however, significant differences in deceleration time (DT), E/A ratio, IRT and the IMP between the two groups (199.5±45.6 msec vs 222.3±54.3 msec, $p<0.01$; 1.4±0.7 vs 0.9±0.2, $p<0.01$; 113.6±30.2 msec vs 134.2±29.6 msec, $p<0.01$; 0.6±0.1 vs 0.8±0.3, $p<0.05$). In HT, there were no differences in EF, SVI, CI, E/A ratio and DT between the NYHA I (Gp I, n=36) and II (Gp II, n=24) groups. However, ET of Gp II was significantly shorter than that of Gp I (259.4±43.5 msec vs 297.8±33.6 msec, $p<0.01$). ICT, IRT and the IMP were significantly increased in Gp II, compared to those of Gp I (64.4±23.9 msec vs 89.4±46.2 msec, $p<0.05$; 120.3±21.0 msec vs 155.2±28.5 msec, $p<0.001$; 0.6±0.2 vs 1.0±0.4, $p<0.001$). There were no differences in heart rate and mean blood pressure between Gp I and Gp II (70.9±11.4/min vs 66.3±11.4/min, $p>0.05$; 138.4±21.2 mmHg vs 131.3±19.9 mmHg, $p>0.05$). These data suggest that the IMP may be a useful parameter and an early indicator of left ventricular dysfunction in essential hypertensive patients with normal systolic function.

Key Words: Doppler echocardiography index, combined systolic and diastolic function, essential hypertension

Approximately one-third of patients with congestive heart failure have impairment of both systolic and diastolic function (McCullagh *et al.* 1972; Cohn *et al.* 1974; Grossmann, 1991; Lenihan *et al.* 1995). Therefore, in the assessment of left ventricular function of these patients, it is important to use the parameters that reflect both systolic and diastolic functions. Previous study has shown that the IMP (Index of Myocardial Performance), a newly-devised Doppler echocardiography index (Tei *et al.* 1995) showing combined systolic and diastolic function, is useful in the assessment of cardiac function in normals and patients with dilated cardiomyopathy. However, there have been no studies on patients with essential hypertension.

The aim of this study was to measure the value of the IMP in normals and to assess the clinical effi-

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cacy of the IMP in the evaluation of left ventricular dysfunction in patients with essential hypertension. It is known that there is a high risk of morbidity or mortality of cardiac complications relating to hypertension which can later lead to congestive heart failure. Therefore, early determination of cardiac dysfunction is of considerable importance in patients with essential hypertension.

MATERIALS AND METHODS

Study population

We analyzed Doppler echocardiograms in 120 subjects with normal sinus rhythm : normals (n=60) and essential hypertensive patients (n=60). Normal subjects were asymptomatic, and had a normal physical examination, chest roentgenogram and electrogram. The hypertensive patients were subdivided by New York Heart Association (NYHA) functional classification (Fletcher *et al.* 1995). Patients who had atrial fibrillation, atrioventricular block or organic valvular disease were excluded.

Echocardiographic examination

Left ventricular ejection fraction (EF) was measured by a modified Quinone's method (Quinones *et al.* 1981). Left ventricular dimensions were measured at mid-ventricular level from a two-dimensional guided M-mode echocardiogram obtained by the parasternal short-axis view.

Hemodynamic parameters and IMP by Doppler echocardiography

The mitral inflow velocity was measured from the apical 4 chamber view with the pulsed wave Doppler sample volume positioned between the mitral leaflet tips during diastole. Peak velocities of mitral inflow in early diastole (E) and late diastole from atrial filling (A) were measured. The deceleration time (DT) was measured as the time from the peak E velocity to the intercept of the deceleration of flow with the baseline.

Left ventricular outflow velocity was measured from the apical 5 chamber view with the pulsed wave Doppler sample volume positioned at the center of the aortic annulus during the systole. The left ventricular outflow tract (LVOT) diameter was measured at the level of the aortic annulus during the systole. Stroke volume was calculated by multiplying the time velocity integral (TVI) by cross-sectional area (CSA) of LVOT. Cardiac output was measured by multiplying stroke volume by heart rate. Stroke volume index (SVI) and cardiac index (CI) were calculated by dividing stroke volume and cardiac output by body surface area, respectively.

In this study, the mitral inflow velocity and left ventricular outflow velocity were concomitantly measured from the apical 3 chamber view with the pulsed wave Doppler sample volume positioned 2 cm apart from the aortic annulus and 1 cm apart from the anterior leaflet of the mitral valve. The mitral closure-to-opening interval (a) was the time from cessation to the onset of mitral inflow. Ejection time (ET) was measured as the duration of left ventricular outflow (b). The isovolumic relaxation time (IRT) was measured from the cessation of left ventricular outflow to the onset of left ventricular inflow. The isovolumic contraction time (ICT) was measured by subtracting IRT from (a-b). Fig. 1 shows a schema for analysis of the Doppler time interval. IMP was calculated as followings (Tei *et al.* 1995): IMP= (ICT+IRT)/ET.

Statistical analysis

Differences between groups in the echo-Doppler

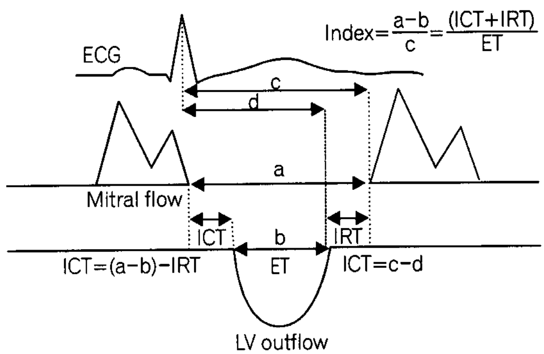

Fig. 1. Schema of Doppler time intervals and new index (ET, Ejection Time; ICT, Isovolumic Contraction Time; IRT, Isovolumic Relaxation Time)

parameters, Doppler time intervals and IMP were compared by the two-sample T-test. Correlation analysis was utilized to evaluate the relationship between IMP and IRT. A value of $p<0.05$ was considered significant in all analyses. All data in the text and tables were presented as mean ±1 standard deviation (SD).

RESULTS

Patient characteristics

The mean age of normals (Group I) was 54.1±15.1 years and in patients with essential hypertension (Group II), it was 57.3±10.2 years. No significant differences of heart rate were observed between Group I and Group II (68.2±10.8/min vs 69.0±11.5/min, $p>0.05$). The mean blood pressure of Group II was significantly higher than that of Group I (135.6±20.8 mmHg vs 106.2±10.8 mmHg, $p<0.05$). In patients with hypertension, there were no significant differences in heart rate and mean blood pressure between the NYHA I (n=36) and NYHA II (n=24) groups (70.9±11.4/min vs 66.3±11.4/min, $p>0.05$; 138.4±21.2 mmHg vs 131.3±19.9 mmHg, $p>0.05$) (Table 1).

Table 1. Clinical characteristics of subjects

Variables	NL (n=60)	HT (n=60)
Age (yrs)	54.1±15.1	57.3±10.2
Sex (M:F)	29 : 31	21 : 39
BSA (m^2)	1.7±0.2	1.7±0.1
HR (bpm)	68.2±10.8	69.0±11.5
SBP (mmHg)	120.6±12.3	157.4±26.2
DBP (mmHg)	77.3±9.3	91.9±13.7
MBP* (mmHg)	106.2±10.8	135.6±20.8
NYHA (N)		
I	60	36
II	0	24
III	0	0
IV	0	0

*: $p<0.05$ BSA: Body Surface Area, DBP: Diastolic Blood Pressure, HR: Heart rate, HT: Hypertension, MBP: Mean Blood Pressure, NL: Normal, NYHA: New York Heart Association, SBP: Systolic Blood Pressure

Parameters reflective of systolic function

There were no significant differences in EF, SVI and CI between Group I and Group II (EF; 70.0±6.3% vs 70.1±6.5%, SVI; 39.8±7.1 *ml*/beat/m^2 vs 43.3±10.8 *ml*/beat/m^2, CI; 2.7±0.6 *L*/m^2 vs 2.9±0.6 *L*/m^2, $p>0.05$) (Table 2). No significant differences in EF, SVI and CI were observed between the NYHA I and NYHA II groups (EF; 70.4±6.7% vs 69.6±6.4%, SVI; 43.6±10.6 *ml*/beat/m^2 vs 43.0±11.4 *ml*/beat/m^2, CI; 3.0±0.6 *L*/m^2 vs 2.8±0.8 *L*/m^2, $p>0.05$) (Table 4). There were no differences in ICT and ET measured by Doppler echocardiography between Group I and Group II (ICT; 66.6±26.0 msec vs 74.4±36.3 msec, ET; 294.0±34.6 msec vs 282.4±42.0 msec, $p>0.05$) (Table 3). However, the ET of the NYHA II group was significantly shorter than that of the NYHA I group (259.4±43.5 msec vs 297.8±33.6 msec, $p<0.01$). ICT was significantly prolonged in the NYHA II group, compared to that of the NYHA I group (89.4

Table 2. Echo-Doppler parameters

Variables	NL (n=60)	HT (n=60)
Mitral flow		
E/A*	1.4±0.7	0.9±0.2
DT (msec)*	199.5±45.6	222.3±54.3
EF (%)	70.0±6.3	70.1±6.5
SVI (ml/beat/m^2)	39.8±7.1	43.3±10.8
CI (l/m^2)	2.7±0.6	2.9±0.6

*: $p<0.01$, CI: Cardiac Index, DT: Deceleration Time, E/A: Peak velocity of diastole(E)/Peak velocity of atrial systole(A), EF: Ejection Fraction, SVI: Stroke Volume Index. Other abbreviations as in Table 1.

Table 3. Doppler time intervals and index of myocardial performance

Variables	NL (n=60)	HT (n=60)
ET (msec)	294.0±34.6	282.4±42.0
IRT (msec)#	113.6±30.2	134.2±29.6
ICT (msec)	66.6±26.0	74.4±36.3
IMP*	0.6±0.1	0.8±0.3

#: $p<0.01$, *: $p<0.05$, ET: Ejection Time, ICT: Isovolumic Contraction Time, IMP: Index of Myocardial Performance, IRT: Isovolumic Relaxation Time. Other abbreviations as in Table 1.

Table 4. IMP, Doppler time interval and echo-Doppler parameters in patients with hypertension

Variables	NYHA I (n=36)	NYHA II (n=24)
IMP#	0.6±0.2	1.0±0.4
DT (msec)	219.0±59.9	227.3±45.7
E/A	0.9±0.3	0.8±0.2
EF (%)	70.4±6.7	69.6±6.4
SVI (ml/beat/m^2)	43.6±10.6	43.0±11.4
CI (L/m^2)	3.0±0.6	2.8±0.8
ICT (msec)*	64.4±23.9	89.4±46.2
IRT (msec)#	120.3±21.0	155.2±28.5
ET (msec)†	297.8±33.6	259.4±43.5

*: $p<0.05$, #: $p<0.001$, †: $p<0.01$. Abbreviations as in Table 1, 2 & 3.

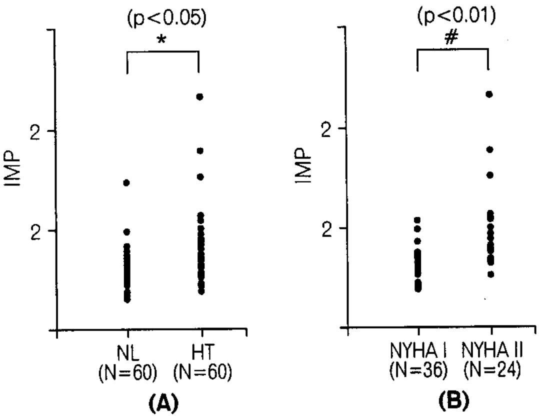

Fig. 2. IMP between NL and HT (Panel A). Panel B shows the IMP between NYHA I and NYHA II of HT (NL, Normals; HT, Hypertensive patients).

±46.2 msec vs 64.4±23.9 msec, $p<0.05$) (Table 4).

Parameters reflective of diastolic function

There were significant differences in deceleration time (DT), E/A ratio and IRT between Group I and Group II (199.5±45.6 msec vs 222.3±54.3 msec, $p<0.01$; 1.4±0.7 vs 0.9±0.2, $p<0.01$; 113.6±30.2 msec vs 134.2±29.6 msec, $p<0.01$) (Table 2 and 3). Significant differences were also observed in the deceleration time and E/A ratio between Group I and the NYHA I group of Group II (199.5±45.6 msec vs 219.0±59.9 msec, $p<0.01$; 1.4±0.7 vs 0.9 ±0.3, $p<0.01$). However, IRT was not significantly prolonged in the NYHA I group of Group II, compared to that of Group I (120.3±21.0 msec vs 113.6±30.2 msec). In patients with hypertension, there were no differences in E/A ratio and DT between the NYHA I and NYHA II groups. However, IRT was significantly prolonged in the NYHA II group, compared with the NYHA I group (120.3±21.0 msec vs 155.2±28.5 msec, $p<0.001$).

Parameter reflective of combined systolic and diastolic function (IMP)

There was a significant difference in IMP between Group I and Group II (0.6±0.1 vs 0.8±0.3, $p<0.05$). Among ICT, IRT and ET, IRT was positively correlated with IMP ($r=0.596$, $p<0.05$). In essential hypertension, IMP was significantly increased in NYHA II, compared to that of NYHA I (0.6±0.2 vs 1.0±0.4, $p<0.001$)(Fig. 2) (Table 4).

DISCUSSION

The principal findings of this study are that (1) a significant difference was observed in IMP between normals and patients with essential hypertension, (2) IMP was significantly higher in the NYHA II group than in the NYHA I group of essential hypertensive patients who had normal systolic function, and (3) IMP may be a useful parameter and early indicator of left ventricular dysfunction in essential hypertensive patients with normal systolic indeces.

The assessment of cardiac function is very important in determining the treatment modality of the patient and in assessing the prognosis of heart disease. Although invasive cardiac catheterization has been regarded as the gold standard in the evaluation of cardiac hemodynamics in the past, echocardiography has become the preferred method for the evaluation of cardiac function and diagnosis of heart failure in recent years (Quinones *et al.* 1981; Nishmura *et al.* 1989). Ejection fraction is the most commonly used parameter for the assessment of systolic function. Though ejection fraction is known to be a good parameter of systolic function, it is not truly reflective of the state of ventricular function. Furthermore, the presence of mitral regurgitation and abnormal shaped ventricles need other adjunctive parameters which may potentially provide useful information in these circumstances.

Also, the assessment of left ventricular diastolic function by Doppler echocardiographic analysis of the diastolic transmitral inflow velocity patterns has been regarded as a useful noninvasive diagnostic modality in the prognosis of patients with congestive heart failure. A pattern of decreased early and increased late mitral flow velocity, known as relaxation abnormality, can be seen with increasing age, myocardial ischemia, essential hypertension and left ventricular hypertrophy. With the progression of left ventricular dysfunction, progressive elevation of left atrial pressure in diastole with reduced isovolumic relaxation will cause left ventricular filling to become restrictive, with blood rapidly forced into the ventricle in early diastole, only to be abruptly decelerated, with little additional filling in mid-diastole and at atrial contraction. Werner *et al.* reported that deceleration time and peak early Doppler velocity were the strongest predictors of survival as compared with systolic function and clinical status in a Cox proportional hazards analysis (Werner *et al.* 1994).

Since the symptoms of heart failure are more prominent during exercise than in a resting state, a cardiopulmonary exercise test is considered to be an another useful modality for the evaluation of cardiac function. However, data from this test have a poor correlation with those of other modalities. The reason being that there are many potential causes which influence cardiac function.

Congestive heart failure is the pathophysiological state in which the heart is unable to pump blood at a rate commensurate with the requirements of the metabolizing tissues or can do so only from an elevated filling pressure. Approximately one-third of patients with congestive heart failure have impairment of both systolic and diastolic function. Therefore, in the assessment of left ventricular function in these patients, it is useful to use predictable parameter including systolic and diastolic functions. An accurate assessment of cardiac function and proper pharmacological treatment in these patients are very important for the improvement of the long-term survival rate.

Previous studies have shown that isovolumic contraction time (ICT) and ejection time (ET) are important in the assessment of systolic function (Weissler, 1968), as well as isovolumic relaxation time (IRT) in the assessment of diastolic function (Grossman *et al.* 1979; Papapietro *et al.* 1979). In 1995, Tei *et al.* suggested that the IMP (Index of Myocardial Performance), a newly-devised Doppler echocardiography index showing combined systolic and diastolic function, was useful in the assessment of cardiac function in normals and patients with dilated cardiomyopathy (Tei *et al.* 1995). Others have also reported that the Doppler right ventricular index appeared to be a useful noninvasive parameter that correlates with symptoms and survival in patients with primary pulmonary hypertension (Tei *et al.* 1996; Yeo *et al.* 1998). Our data show that the IMP is significantly increased in patients with essential hypertension compared to normals, as well as in the NYHA II group compared to the NYHA I group of essential hypertensive patients who have normal systolic function. In patients with essential hypertension, an increase in ICT resulting from reduced contractility is associated with the progression of heart failure. In contrast, while prolonged relaxation is initially associated with an increase in IRT, a progressively deteriorating degree of ventricular dysfunction will shorten this interval because of the dependence of IRT on factors other than active relaxation, such as left atrial pressure and the degree of mitral regurgitation. As well, ET is progressively shortened as the degree of ventricular dysfunction evolves (Burwash *et al.* 1993). Thus, with worsening left ventricular dysfunction in patients with essential hypertension, IMP increases disproportionately to any changes in the individual components of the index. It is likely that an increase in IRT contributes more to a change in IMP than an increase in ICT or a decrease in ET. Since the IMP has more systolic parameters such as ICT and ET than diastolic parameters such as IRT, the IMP is relatively more reflective of systolic function than diastolic function. Therefore, it is likely that cardiac function could not be accurately assessed by the IMP in patients with restrictive cardiomyopathy or hypertrophic cardiomyopathy who mainly have diastolic dysfunction. Though it is known that the measurement of pulmonary vein inflow could be done in only about 70% of patients and influenced by compliance of the left atrium, it deserves to be measured in the assessment of diastolic dysfunction of patients with essential hypertension.

In conclusion, our data show that the IMP is technically easy to obtain by Doppler echocardiography in normals and patients with essential hypertension. In patients with essential hypertension showing normal systolic function (ie; normal EF, SVI and CI), only the IMP was significantly higher than in normals. Also, despite no significant differences in EF, SVI and CI, the IMP with ICT and IRT were significantly higher in NYHA II group than in NYHA I group of essential hypertensive patients. However, no differences were observed in parameters, except deceleration time and E/A ratio, between normals and NYHA I group. According to the results of this study, it is likely that the IMP may be a useful parameter and an early indicator of left ventricular dysfunction in essential hypertensive patients with normal systolic function. Therefore, in patients with hypertension who clinically complain of dyspnea on exertion, or even asymptomatic patients with hypertension who have normal EF on echocardiography, the IMP combining systolic and diastolic time interval is a promising new index for the assessment of cardiac dysfunction. However, further follow-up study is necessary to demonstrate whether or not, the IMP will be a useful parameter in the assessment of cardiac function in these patients.

LIMITATION OF THE PRESENT STUDY

Any other clinical factors which have an influence on cardiac function, such as systolic and diastolic blood pressure, systemic resistance, presence of atrioventricular block and drugs which influence a patient's heart rate, may potentially alter the value of the IMP. The fact that factors which can influence the IMP could not be evaluated remains to be desired.

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