Evaluation of Right Ventricular Function in Patients With Congestive Left Heart Failure by the Doppler Derived Total Cardiac Performance Index (TEI index)

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Abstract

Background. This study aimed to assess the serial changes of right ventricular (RV) function in patients with congestive heart failure (CHF) from the acute to the convalescent stage using the Doppler derived total cardiac performance index (TEI index).

Methods. Sixteen patients (11 men; mean age, 67 years) with acute left heart failure and sinus rhythm were studied by two-dimensional and Doppler echocardiography during the acute and convalescent stages of CHF. The ratio of early to late diastolic filling velocity (E/A) of both ventricles and the volume and ejection fraction of the left ventricle (LV) were measured. The isovolumic contraction (RVICT), relaxation times (RVIRT), and the ejection time (RVET) were measured from the recordings of the RV inflow or outflow velocities and the electrocardiogram. The RV TEI index was calculated as (RVICT + RVIRT) / RVET.

Results. During the acute stage, the RVICT and RVIRT were prolonged, the RVET was shortened, and subsequently the RV TEI index was increased. As the condition improved, the RVICT and RVIRT were shortened, the RVET was prolonged, and the RV TEI index was significantly decreased along with a decrease in the LV volume and an increase in the LV ejection fraction.

Conclusions. The RV TEI index seems to be useful for evaluating global RV function in patients with congestive left heart failure.

Key words: congestive heart failure, right ventricular function, TEI index

Introduction

The Doppler derived total cardiac performance index (TEI index), which combines systolic and diastolic cardiac function, is now widely used in the clinical practice because of easy quantitative assessment, high reproducibility, and less dependency on heart rate and blood pressure [1-3]. The assessment of right ventricular (RV) function remains difficult and challenging. For example, echocardiographic measurement of the RV volume and ejection fraction is difficult because the shape of the RV is more complex than that of the left ventricle (LV) [4,5]. Thus, the assessment of RV function in the setting of left heart failure has often been ignored, with only a few studies including RV filling [6-8]. The TEI index has been already confirmed to be applicable to the assessment of overall RV function as well as overall LV function [9-13] except for a few unusual situations [14, 15].

This study aimed to assess the serial changes of RV function in patients with congestive left heart failure using the TEI index.
Methods

Subjects

The study subjects were comprised of 16 patients (11 men, 5 women; mean age, 67 ± 12 years, range: 47 - 81 years) with acute left heart failure and sinus rhythm who were admitted to our hospital from May 2004 to April 2005. Underlying diseases were old myocardial infarction in 8 patients, idiopathic dilated cardiomyopathy in 5 patients, and hypertensive heart disease in 3 patients. Old myocardial infarction was defined as a myocardial infarction that had occurred at least 3 months previously. In the acute stage of heart failure, all patients were symptomatic (NYHA class III in 12 patients and class IV in 4 patients) and had pulmonary edema on the plain chest roentgenogram. All patients were hospitalized and studied by echocardiography during the acute and the convalescent stages, with a mean interval of 21 ± 8 days. The protocol was approved by the institutional ethics committee, and informed consent was obtained from all enrolled patients.

Echocardiography

Echocardiographic examinations were performed with the patient in the left lateral decubitus position using a commercially available ultrasound system (Sequoia 512 echocardiographic imaging system, Siemens, USA) equipped with a 3.5-MHz transducer. Recordings were made during held expiration. Two-dimensional echocardiographic images were obtained using the apical long-axis view. Left ventricular end-diastolic and end-systolic volumes (LVEDV and LVESV, respectively) were determined using Simpson’s method, and the LV ejection fraction (LVEF) was calculated by (LVEDV - LVESV) / LVEDV × 100 (%).

The LV inflow velocity pattern was obtained from the apical long-axis view with the pulsed wave Doppler sample volume positioned at the tips of the mitral leaflets during diastole. The peak velocities of early diastole (E) and late diastole (A), their ratio (E/A), and the deceleration time of the E wave were determined from the LV inflow recordings. The RV inflow velocity pattern was obtained from the parasternal short-axis view with the pulsed wave Doppler sample volume positioned at the tips of the tricuspid leaflets during diastole. E, A, and E/A were determined from the RV inflow recordings. The RV outflow velocity pattern was obtained from the same view with the Doppler sample volume placed just below the pulmonic valve. These RV flow velocity patterns were recorded with an electrocardiogram (ECG) at a paper speed of 50 or 100 mm/sec. The time interval between the cessation and onset of RV inflow (a) was measured. The RV ejection time (RVET) was measured as the time interval from onset to cessation of RV outflow velocity (b). The isovolumic relaxation time (RVIRT) was measured as the difference between the time interval from the peak of the ECG R wave to the onset of RV inflow (c) and the time interval from the peak of the ECG R wave to the cessation of RV outflow (d). The isovolumic contraction time (RVICT) was calculated by subtracting RVIRT from (a - b). The RV TEI index was calculated as (a - b) / b [14] (Figure 1). Each measurement was carried out for 5 consecutive beats and averaged.

Fig. 1. Measurements of Doppler time intervals of the right ventricle (RV)

ECG = electrocardiogram, E and A = peak early and late diastolic velocity waves of the right ventricular inflow, respectively.
The severity of tricuspid regurgitation (TR) was estimated as grade 1 to 4 by the extent of color Doppler regurgitant signal in the right atrium. We also estimated RV systolic pressure from the peak velocity (V) of TR by continuous wave Doppler echocardiography according to the formula $4 \cdot V^2 + 10$ (mmHg) [16].

**Statistical analysis**

All data are expressed as the mean ± SD. Comparisons of measurements between the acute and the convalescent stages of left heart failure were performed with the Student’s paired t test. The correlations of the changes in RV TEI index with the changes in other echocardiographic parameters from acute to convalescent stage of heart failure were determined using linear regression analysis. A p value < 0.05 was considered statistically significant.

### Results

#### Baseline characteristics of the subjects

Clinical characteristics of the 16 patients during the acute stage of heart failure are shown in Table 1. All patients had dilated LV with decreased contraction, pseudonormal or restrictive LV filling dynamics, and mild grade MR and/or TR. Estimated RV systolic pressure in 12 patients with TR was mildly elevated.

#### Clinical and left heart parameters

Comparisons of the clinical and left heart parameters between the acute and the convalescent stages of heart failure are shown in Table 2. The NYHA functional class improved significantly, and the plasma level of BNP decreased significantly with the improvement of heart failure. Heart rate was slightly higher in the acute stage than in the convalescent stage, but statistically insignificant. There was no significant difference in systolic blood pressure between both stages. The LVEDV was significantly lower, and the LVEF was significantly higher in the convalescent stage than in the acute stage. As for the LV inflow velocity, the E/A ratio decreased, and the E wave deceleration time prolonged significantly with the improvement of heart failure.

#### Right heart parameters

Comparisons of the right heart parameters between the acute and the convalescent stages of heart failure are shown in Table 3. The E/A ratio of RV inflow velocity increased significantly with the improvement of heart failure. Both RVICT and RVIRT significantly shortened in the convalescent stage compared with the acute stage. The RVET significantly prolonged with the improvement of heart failure. As a result, the RV TEI index significantly decreased in the convalescent stage compared with the acute stage.

As for the TR, we were able to detect the TR signal in 12 of 16 patients during the acute stage of heart failure. The TR signal disappeared in 6 of these 12 patients during the convalescent stage. Both the TR

### Table 1. Patient characteristics

| Age (years) | 67±12 |
| Sex (M/F) | 11 / 5 |
| NYHA class (/4) | 3.0±1.3 |
| Heart rate (bpm) | 81±10 |
| Systolic BP (mmHg) | 118±15 |
| Diastolic BP (mmHg) | 72±9 |
| LVEDV (ml) | 174±30 |
| LVEF (%) | 38±11 |
| LVIF-E/A | 1.6±0.4 |
| LVIF-E DcT (msec) | 135±26 |
| Presence of MR | 13 / 16 (81%) |
| Grade of MR (/4) | 0.9±0.7 |
| Presence of TR | 12 / 16 (75%) |
| Grade of TR (/4) | 1.0±0.6 |
| RVSP (mmHg) | 48±7 (n=12) |

NYHA=New York Heart Association class; HR=heart rate; BP=blood pressure; LVEDV=left ventricular end-diastolic volume; LVEF=left ventricular ejection fraction; LVIF=left ventricular inflow; E=early diastolic filling velocity; A=late diastolic filling velocity; DcT=deceleration time; MR=mitral regurgitation; TR=tricuspid regurgitation; RVSP=right ventricular systolic pressure; n=number of patients.

### Table 2. Comparison of clinical and left heart parameters between the acute and the convalescent stages of CHF

<table>
<thead>
<tr>
<th>NYHA (/4)</th>
<th>BNP (pg/ml)</th>
<th>HR (bpm)</th>
<th>Systolic BP (mmHg)</th>
<th>LVEDV (ml)</th>
<th>LVEF (%)</th>
<th>LVIF-E/A</th>
<th>LVIF-E DcT (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute stage (n=16)</td>
<td>3.0±1.3**</td>
<td>543±337**</td>
<td>81±10</td>
<td>118±15</td>
<td>174±30**</td>
<td>38±11*</td>
<td>1.6±0.4**</td>
</tr>
<tr>
<td>Convalescent stage (n=16)</td>
<td>1.3±0.5</td>
<td>134±99</td>
<td>74±8</td>
<td>123±14</td>
<td>142±18</td>
<td>45±12</td>
<td>0.8±0.3</td>
</tr>
</tbody>
</table>

BNP=brain natriuretic peptide. Other abbreviations are as in Table 1.

**p<0.001, *p<0.01 vs. convalescent stage**
grade and the RV systolic pressure decreased significantly with the improvement of heart failure in both the comparison between 12 patients in the acute stage and 6 patients in the convalescent stage and the comparison between 6 patients with both recordings of TR signal in the acute and convalescent stage.

Correlations between the changes in RV TEI index and the changes in other echo-Doppler variables

Correlations between the changes in RV TEI index and the changes in other echo-Doppler variables from acute to convalescent stage of CHF are shown in Table 4. The changes in RV TEI index directly correlated with the changes in RVIRT (r=0.70, p<0.001) (Fig. 1, right) and RVICT (r=0.61, p<0.01) (Fig. 1, left) but did not significantly correlate with the changes in RVET, E/A ratio of the RV inflow velocity, and parameters of LV inflow velocity.

Representative case presentation

Figure 2 shows RV inflow and outflow velocity patterns during the acute and convalescent stage of congestive heart failure in a 50-year-old man with dilated cardiomyopathy. The LVEDV decreased from 190 to 175 ml, and the LVEF increased from 28 to 35 % with improvement of heart failure. During the acute decompensated stage, the RVIRT (106 msec) and RVICT (54 msec) prolonged, the RVET (240 msec) shortened, and the RV TEI index (0.67) was high. With improvement in the clinical condition, the RVIRT and RVICT shortened to 78 msec and 42 msec, the RVET prolonged to 270 msec, and the RV TEI index decreased to a normal range (0.30).

Discussion

Observations obtained in this study were summarized as follows: the RVICT and RVIRT prolonged, the RVET shortened, and subsequently the RV TEI index increased in the acute decompensated stage of congestive heart failure (CHF). As the clinical condition improved, the RVICT and RVIRT shortened, the RVET prolonged, and the RV TEI index significantly decreased.

In the acute stage of CHF, pulmonary artery pressure and pulmonary vascular resistance would be elevated. It has been reported that a high afterload impairs ventricular relaxation and early ventricular filling [17].

Ohta et al. [8] serially assessed the left and right ventricular filling in patients with CHF. According to their paper, the LV filling had a pseudonormal or restrictive pattern whereas the RV filling had an abnormal relaxation pattern in the acute stage of CHF. From the acute to the convalescent stage, LV and RV filling patterns changed in opposite directions. In the convalescent stage, LV filling E wave decreased and A wave increased whereas RV filling E wave increased.

<table>
<thead>
<tr>
<th>RVIF-E/A</th>
<th>RVET</th>
<th>RVICT</th>
<th>RVIRT</th>
<th>RV TEI index</th>
<th>TR grade (1)</th>
<th>TR grade (2)</th>
<th>RVSP (1)</th>
<th>RVSP (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute stage (n=16)</td>
<td>0.9±0.3*</td>
<td>285±34**</td>
<td>57±18***</td>
<td>86±16***</td>
<td>0.52±0.13***</td>
<td>1.0±0.6*</td>
<td>1.2±0.5*</td>
<td>48±7*</td>
</tr>
<tr>
<td>Convalescent stage (n=16)</td>
<td>1.1±0.5</td>
<td>302±32</td>
<td>42±14</td>
<td>62±16</td>
<td>0.35±0.18</td>
<td>0.6±0.4</td>
<td>0.6±0.4</td>
<td>37±6</td>
</tr>
</tbody>
</table>

RVIF=left ventricular inflow; RVET=ejection time of the right ventricle; RVICT=isovolumic contraction time of the right ventricle; RVIRT=isovolumic relaxation time of the right ventricle. Other abbreviations are as in Table 1. TR grade (1) and RVSP (1) were comparisons of all cases with TR signal. TR grade (2) and RVSP (2) were comparisons of 6 patients with both recordings of TR signal.

**p<0.001, *p<0.01, *p<0.05 vs. convalescent stage

Table 3. Comparison of right heart parameters between the acute and the convalescent stages of CHF

Table 4. Correlations between the changes in RV TEI index and other echocardiographic variables from acute to convalescent stage of CHF

<table>
<thead>
<tr>
<th>RVIF-E/A</th>
<th>r</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVET</td>
<td>-0.41</td>
<td>ns</td>
</tr>
<tr>
<td>RVICT</td>
<td>0.61</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>RVIRT</td>
<td>0.70</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>LVIF-E/A</td>
<td>0.25</td>
<td>ns</td>
</tr>
<tr>
<td>LVIF-E</td>
<td>0.18</td>
<td>ns</td>
</tr>
<tr>
<td>LVIF-E DcT</td>
<td>-0.32</td>
<td>ns</td>
</tr>
</tbody>
</table>

ns=not significant. Other abbreviations are as in Tables 1 and 3.
Figure 2. Examples of pulsed Doppler inflow and outflow velocity waves of the right ventricle (RV) during the acute (A) and convalescent stage (B) of congestive heart failure in a 50-year-old man with dilated cardiomyopathy. As the patient's clinical condition improved, the RV inflow (RVIF) profile changed from an E < A to E > A pattern, the isovolumic contraction time (ICT) shortened from 54 to 42 msec, the isovolumic relaxation time (IRT) shortened from 106 to 78 msec, and the RV ejection time (RVET) prolonged from 240 to 270 msec. Resultantly, the RV TEI index markedly decreased from 0.67 to 0.30. RVOF = right ventricular outflow velocity wave; E, A = early and late diastolic velocity wave of the right ventricular inflow, respectively.

Figure 3. Correlations between the changes in RV TEI index ($\Delta$RV index) and the changes in isovolumic contraction time ($\Delta$RVICT, left panel) and isovolumic relaxation time of the RV ($\Delta$RVIRT, right panel) from acute to convalescent stage of heart failure. Both panels show significantly direct correlations between these parameters.
and A wave decreased. These changes were accompanied by clinical improvement. They concluded that the changes in the RV filling pattern was likely to be related to changes in RV afterload, ventricular interaction, and external constraint rather than a change in RV filling pressure.

Kibira et al. [18] assessed the relationship between the isovolumic time intervals and TEI index of the RV and the right heart hemodynamic parameters in patients with congestive left heart failure. They postulated that both the RVICT and RVIRT prolonged as the reflection of the respective elevation of diastolic and systolic pressures of the pulmonary artery, and the RV TEI index resultanty increased in the acute decompensated stage of CHF.

Tei et al. [9] assessed the clinical value of the Doppler RV TEI index, combining systolic and diastolic time intervals of the right heart, in evaluating global RV function in patients with primary pulmonary hypertension (PPH). They described that both the RVICT and RVIRT prolonged, and the RVET shortened significantly in patients with PPH compared with normal subjects. They suggested that the prolonged RVICT may be caused by RV systolic dysfunction and earlier onset of RVICT in the setting of elevated RV end-diastolic pressure, and the prolonged RVIRT may be caused by RV diastolic dysfunction.

In the present study, the changes in RV TEI index from acute to convalescent stage of CHF directly correlated with the changes in RVICT and RVICT but did not significantly correlate with the changes in RVET. In addition, the RV systolic pressure, estimated by continuous Doppler echocardiography, significantly increased in the acute stage of CHF as compared to the convalescent stage.

The above described previous reports and the results of this study suggest that the increase in RV TEI index in the acute decompensated stage of CHF may be due to a disturbed relaxation and a decreased contraction of the RV myocardium mainly caused by an increasing afterload against the RV.

Tei et al. [19] evaluated the effect of thermal therapy for CHF using the Doppler TEI index of both ventricles. They reported that pulmonary vascular resistance, pulmonary capillary wedge pressure, and right atrial pressure decreased significantly after thermal therapy with a concomitant decrease in RV TEI index. Yeo et al. [20] reported that the RV TEI index is a useful predictor of adverse outcomes in patients with primary pulmonary hypertension. Therefore, the Doppler TEI index appears to be a useful parameter of global function and hemodynamic condition of the right heart. The present results provide additional information for the estimation of a patient’s hemodynamic condition and a clinical course of recovery from CHF.

Study limitations

There are some limitations in this study. First, the number of study patients is small. However, each measured parameter changed to the same direction after the treatment of heart failure in all patients. The second limitation is that we have no data of intracardiac pressures, particularly LV filling pressure, during the acute and convalescent stage of CHF. However, the mitral inflow velocity profile showed a restrictive or pseudonormal pattern in the acute stage, and it changed into a relaxation failure pattern in the convalescent stage of CHF in all patients. Thus, it appears to be obvious that the LV filling pressure is elevated in the acute stage and decreases within normal range in the convalescent stage of CHF.

Conclusions

The RV TEI index increased in the acute decompensated stage of congestive left heart failure and significantly decreased as the clinical condition improved. The high RV TEI index at the acute stage was thought to be due to the prolongation of RVICT and RVIRT caused by an increased afterload against the RV. The RV TEI index may be useful for evaluating overall RV function during congestive left heart failure.

References

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