Original investigations

Evaluation of Right Ventricular Function in Patients With Complete Right Bundle-branch Block Using Total Cardiac Performance Index (TEI Index)

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Abstract

Background. We aimed to assess right ventricular (RV) function in patients with complete right bundle branch block (CRBBB) using noninvasive techniques.

Methods. The studied subjects were 29 consecutive patients with CRBBB aged over 40 years (mean: 66 years). Six patients had hypertension; the other 23 patients had no cardiovascular disorders. Twenty age-matched healthy subjects (mean: 68 years) served as the controls. The RV volumes at end-diastole (RVEDV) and end-systole were measured via apical four-chamber view, and the RV ejection fraction (RVEF) was calculated. The isovolumic contraction (ICT) and relaxation times (IRT) and the ejection time (RVET) were measured using the recordings of RV inflow or outflow velocities and the electrocardiogram. The total cardiac performance index (TEI index) was calculated as $(ICT + IRT) / RVET$.

Results. The patients with CRBBB were divided into two groups based on the mean + 2 standard deviations of RV TEI index (≤ 0.40) in the controls: the low value group (23 patients with TEI index ≤ 0.40) and the high value group (6 with TEI index > 0.40). The RVEDV was larger and RVEF lower in the high value group compared to the low value group. The ICT and IRT were prolonged while the RVET was shortened in the high value group when compared with the low value group. Arrhythmic events, such as paroxysmal atrial fibrillation or multiple ventricular premature beats, frequently occurred in the high value group (50 %) as compared to the low value group (4 %, $p < 0.01$).

Conclusion. RV dysfunction or arrhythmic events may occur in some patients with CRBBB, and the TEI index may be useful for the detection and evaluation of these patients.

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Key words: complete right bundle branch block, right ventricular function, TEI index

Introduction

Complete left bundle branch block (CLBBB) often accompanies organic heart diseases [1-4]. On the other hand, complete right bundle branch block (CRBBB) can be observed in a patient without evi-

dence of organic heart disease, and it does not appear to influence the subsequent clinical course [2-5]. It is fairly well established that there are two forms of CRBBB: one is interruption of the main right branch of the bundle of His, termed proximal block, and the other in which the terminal ramifications of the right bundle are affected, termed distal block [6, 7]. However, there have been few studies on the evaluation of right ventricular (RV) function in patients with CRBBB [8-10].

The Doppler TEI index, total cardiac performance index, is now widely used in the clinical practice because of applicability in the evaluation of both left and right ventricular functions and high reproducibility [11-13].

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In this study, we aimed to assess the right ventricular function in patients with CRBBB using noninvasive techniques containing this TEI index.

Methods

Subjects

The studied subjects were 29 patients with CRBBB, 14 men and 15 women aged over 40 years, ranging from 45 to 86 (mean 66) years, selected from consecutive 58 CRBBB patients diagnosed by the standard 12 leads electrocardiogram (ECG) in our institution between January 2002 and December 2004. Patients with pulmonary hypertension, congenital heart disease, myocardial infarction, and cardiomyopathy were excluded. Six patients had hypertension; the other 23

patients had no evidence of cardiovascular disorder. Twenty age-matched healthy subjects, 10 men and 10 women aged 57 to 82 (mean 68) years, served as the control group. The protocol was approved by the institutional ethics committee, and informed consent was obtained from all enrolled patients.

Echocardiography and Doppler echocardiography

Echocardiography and Doppler echocardiography were performed with the patient in the left lateral decubitus position using a Sequoia 512 (Siemens, USA) or SSD-2200 (Aloka, Japan) echocardiographic imaging system equipped with a 2.5- or 3.5-MHz transducer and running the tissue Doppler imaging program. Recordings were made during held expiration. The end-diastolic and end-systolic volumes of the RV

Fig. 1. Measurements of the right ventricular (RV) volume
The volumes were measured using the apical four-chamber view and Simpson's method at end-diastole (upper panels) and end-systole (lower panels), and the RV ejection fraction was calculated. LA=left atrium, LV=left ventricle, RA=right atrium.

Fig. 2. Measurements of Doppler time intervals of the right ventricle (RV)

The interval from cessation to onset of RV inflow (a) was measured. The RV ejection time (RVET) was measured as the interval from onset to cessation of RV outflow (RVOF) (b). The isovolumic relaxation time (IRT) was measured as the difference between the interval from the peak of the ECG R wave to the onset of RV inflow (RVIF) (c) and the interval from the peak of the ECG R wave to the cessation of RV outflow (d). The isovolumic contraction time (ICT) was calculated by subtracting IRT from (a – b). The RV TEI index was calculated as (a – b) / b. ECG=electrocardiogram, E and A=peak early and late diastolic velocity waves of the RV inflow, respectively.

(RVEDV and RVESV) (Figure 1) and the left ventricle (LVEDV and LVESV) were measured on the apical four-chamber view using the Simpson's method, and the ejection fraction of the RV (RVEF) and the LV (LVEF) was calculated from $(EDV - ESV) / EDV \times 100$ (%). The right atrial volume (RAV) was also measured in the same view using the Simpson's method.

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. The RV outflow velocity pattern was obtained from the same view with the Doppler sample volume placed just below the pulmonic valve. These velocity patterns were recorded with an 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 [11] (Figure 2). Each measurement was carried out for 5 consecutive beats and averaged.

Fig. 3. Measurements of the tricuspid annulus velocity

The peak systolic (Sa) and early diastolic (Ea) velocities were measured from the tricuspid annulus velocity pattern (right panel) recorded on the apical four-chamber view using pulsed Doppler tissue imaging by placing a sample volume at the lateral tricuspid annulus (left panel). LA=left atrium, LV=left ventricle, RA=right atrium, RV=right ventricle.

The tricuspid annulus velocity along the long-axis was measured on the apical 4-chamber view using pulsed tissue Doppler imaging (TDI) by placing a sample volume at the lateral portion of the tricuspid valve annulus. A sample volume with a fixed length of 4 mm was used. Peak systolic (Sa) and peak early diastolic (Ea) velocities were measured from the tricuspid annulus velocity pattern (Figure 3).

The presence of tricuspid regurgitation (TR) was determined by color Doppler flow imaging, and its severity was assessed semiquantitatively as minimal (1/4), mild (2/4), moderate (3/4), and severe (4/4) based on both length and extent of the regurgitant jet. The RV to RA pressure gradient was calculated from the TR jet velocity recorded by continuous wave Doppler echocardiography using the modified Bernoulli equation.

Evaluation of arrhythmia

Arrhythmic events were evaluated by 3 minutes ECG recordings in 20 patients without symptoms suggesting arrhythmia and evaluated by ambulatory Holter ECG recordings in 6 patients with symptoms.

Statistical analysis

Mean values and standard deviations (SD) were used to describe the distributions for continuous variables; and frequencies and percentages for categorical variables. Differences among the groups were evaluated with χ^2 test for categorical variables and the analysis of variance test for continuous variables. All analyses were performed using Statview 4.0 statistical software. *P*-values of 0.05 or less were considered statistically significant.

Results

Subgroups of CRBBB

The patients with CRBBB were subdivided into the following two groups based on the mean value + 2SD of the RV TEI index (=0.40) in the controls: the low value group (23 patients) had RV TEI index ≤ 0.40 , and the high value group (6 patients) had RV TEI index > 0.40 .

Representative case presentation

Figure 4 shows two-dimensional echocardiograms and Doppler echocardiograms from a 64-year-old man

Fig. 4. Two-dimensional echocardiograms and Doppler echocardiograms from CRBBB patients with high RV TEI index (upper panels, 64-year-old man) and low RV TEI index (lower panels, 53-year-old man). The RV TEI index was 0.51 ($a=434$ msec, $b=288$ msec) in the upper panels (B and C) and 0.31 ($a=428$ msec, $b=332$ msec) in the lower panels (F and G), respectively. In a high value patient as compared to a low value patient, the right ventricle (RV) was enlarged (RVEDV=52 ml vs. 34 ml) (panels A and E); the RV ejection fraction was decreased (46 % vs. 60 %) (panels A and E); and the tricuspid annular Sa and Ea velocities were decreased (9.2 cm/sec and 4.4 cm/sec vs. 16.7 cm/sec and 13.4 cm/sec, respectively) (panels D and H).

in the high value group (upper panels) and a 53-year-old man in the low value group (lower panels). The RV TEI index was 0.51 in the upper panels and 0.31 in the lower panels, respectively. In a high value patient as compared to a low value patient, the RV was enlarged; the RVEF was decreased; and the tricuspid annular Sa and Ea velocities were decreased.

Clinical findings and left ventricular indices

The comparison of clinical findings and left ventricular indices between the high and low value subgroups of the CRBBB patients is shown in Table 1. There were no significant differences in age, presence of underlying heart disease, LVEDV, and LVEF between the two subgroups. No patients had hypertrophy of the LV wall. The LV wall thickness (LVWT), measured from the sum of septal and posterior wall thickness on the two-dimensional echocardiography, showed no significant difference between the two subgroups.

Echocardiographic and Doppler echocardiographic variables

Table 2 shows the comparison of echocardiographic and Doppler echocardiographic variables of the RV

among the two CRBBB groups and the control group. Tricuspid regurgitation (TR) was present in 9 of 23 patients (39 %) in the low value group (grade 1/4, 8 patients; grade 2/4, one patient), in 4 of 6 patients (67 %) in the high value group (grade 1/4, 3 patients; grade 2/4, one patient), and in 5 of 20 (25 %) in the control group (grade 1/4). There was no significant difference in the grade of TR among the three groups. Pressure gradient between the RV and the RA derived from the peak velocity of TR showed no significant difference among the three groups. The RVEDV and the RAV were significantly larger and the RVEF was significantly lower in the high value group than in the low value group. These three variables of the low value group showed no significant difference from those of the control group.

Doppler time intervals and TDI variables

Table 3 shows the comparison of Doppler time intervals and TDI variables among the two CRBBB groups and the control group. The RVICT and RVIRT were significantly prolonged, and the RVET was significantly shortened in the high value group as compared to the low value group. In addition, the tricuspid annular

Table 1. Comparison of clinical findings and left ventricular indices between the two subgroups of CRBBB

	Age (years)	HR (bpm)	Underlying disease + / -	LVEDV (ml)	LVEF (%)	LVWT (mm)
Low value group (TEI index ≤ 0.40) (n=23)	66 $\pm$ 14	63 $\pm$ 8	5 / 18	74 $\pm$ 18	64 $\pm$ 11	18.4 $\pm$ 2.0
High value group (TEI index > 0.40) (n=6)	67 $\pm$ 13	65 $\pm$ 8	1 / 5	82 $\pm$ 20	65 $\pm$ 8	17.9 $\pm$ 1.8

HR=heart rate; LVEDV=left ventricular end-diastolic volume; LVEF=left ventricular ejection fraction.; LVWT=left ventricular wall thickness; n=number of patients.

Table 2. Comparison of echocardiographic and Doppler echocardiographic variables among the two CRBBB subgroups and the control group

	RVEDV (ml)	RVEF (%)	RAV (ml)	TR grade (/ 4)	TR-PG (mmHg)
Control group (n=20)	31 $\pm$ 9	58 $\pm$ 6	40 $\pm$ 8	0.5 $\pm$ 0.4	22 $\pm$ 4 (n=5)
Low value group (n=23)	34 $\pm$ 9	55 $\pm$ 9	44 $\pm$ 6	0.6 $\pm$ 0.4	25 $\pm$ 6 (n=9)
High value group (n=6)	50 $\pm$ 18*	46 $\pm$ 7*	68 $\pm$ 9*	0.6 $\pm$ 0.6	23 $\pm$ 3 (n=4)

RVEDV=right ventricular end-diastolic volume; RVEF=right ventricular ejection fraction; RAV=right atrial volume; TR=tricuspid regurgitation, PG=pressure gradient; n=number of patients.

*p<0.01 vs. other groups.

Table 3. Comparison of Doppler time intervals and TDI variables among the two CRBBB subgroups and the control group

	RVICT (msec)	RVIRT (msec)	RVET (msec)	TDI-Sa (m/sec)	TDI-Ea (m/sec)	RV TEI index
Control group (n=20)	46 ± 13	45 ± 11	320 ± 30	0.15 ± 0.03	0.12 ± 0.04	0.28 ± 0.06
Low value group (n=23)	50 ± 15	40 ± 16	324 ± 31	0.15 ± 0.02	0.11 ± 0.04	0.29 ± 0.05
High value group (n=6)	70 ± 21*	61 ± 13*	295 ± 27*	0.11 ± 0.04*	0.06 ± 0.03*	0.49 ± 0.07*

RVICT=isovolumic contraction time of the right ventricle; RVIRT=isovolumic relaxation time of the right ventricle; RVET=ejection time of the right ventricle; TDI=tissue Doppler echocardiography; Sa=systolic velocity of the tricuspid annulus; Ea=early diastolic velocity of the tricuspid annulus; n=number of patients. *p<0.01 vs. other groups.

Sa (TDI-Sa) and Ea (TDI-Ea) velocities were significantly lower in the high value group than in the low value group. Each variable of the low value group showed no significant difference from that of the control group.

Arrhythmic events

Arrhythmic events, such as paroxysmal atrial fibrillation or multiple ventricular premature beats, occurred significantly frequently in the high value group (3 of 6 patients, 50 %) as compared to the low value group (one of 23 patients, 4 %) ($p<0.01$). The shape of ventricular premature beat was LBBB pattern in all 4 patients.

Discussion

Observations obtained in this study were summarized as follows: the high RV TEI index group (>0.40) had a greater sized RV with decreased systolic and diastolic function and showed a high incidence in the occurrence of paroxysmal atrial fibrillation or multiple ventricular premature beats as compared to the low TEI index group (≤ 0.40).

The Doppler TEI index, which was reported by Tei C. et al. [11] in 1995, is now widely recognized as an index reflecting total cardiac performance combining systolic and diastolic function. It is easily measured, highly reproducible, and clinically applicable in the evaluation of not only left but also right ventricular function [12, 13] except for a few unusual situations [14, 15].

CRBBB is usually discovered in patients without evidence of organic heart disease, and it does not appear to influence the subsequent clinical course [2-5]. It is now fairly well established that there are two forms of CRBBB: one is interruption of the main right branch of

the bundle of His, termed proximal block, and the other is the disturbance of the terminal ramifications of the right bundle, termed distal block [6, 7]. Brooks et al. [16] and Dancy et al. [17] speculated on the basis of the time analysis of right-sided systolic events using echophonocardiography that the proximal block is relatively isolated and benign, but the distal block is associated with diffuse myocardial disease which was likely to be more widespread and progressive. In the group thought to have proximal block, these authors found that the right-sided delay was confined to prolongation of the time interval between mitral valve closure and tricuspid valve closure on the echocardiogram. In the group thought to have distal block, the positive dP/dt of the RV pressure rise was decreased, and the delay was mainly between tricuspid valve closure and pulmonary valve opening (i.e., RVICT). In addition, Dancy et al. [17] described that 12 out of 13 of CRBBB with distal delay but only one out of 14 of CRBBB with proximal delay had episodes of syncope or near syncope.

The group with high RV TEI index in this study, which showed decreased RVEF and prolonged RVICT, is thought to be similar to the distal block as speculated by Brooks and Dancy et al. [16, 17]. Systolic long axis velocity of the lateral tricuspid annulus (Sa) is reported to be useful for assessing RV systolic function in a broad patient population [18] and in patients with inferior myocardial infarction [19]. Decreased Sa velocity of the high RV TEI index group in this study also suggests deterioration of RV systolic function. On the contrary, the group with low RV TEI index, which showed normal values of RVEF, RVICT, and tricuspid annulus Sa velocity, is thought to be similar to the proximal block as speculated by Brooks and Dancy et

al. [16, 17]. In general, deterioration of myocardial contractility may be accompanied by disturbance of active myocardial relaxation. Fukuda et al. [20] reported that the tricuspid annulus Ea velocity decreases with age and reflects RV diastolic function more accurately than RV inflow velocity. Thus, prolonged RVIRT and decreased Ea velocity of the tricuspid annulus in the group with high RV TEI index are thought to be the reflection of disturbed RV relaxation.

The following reasons were considered why the incidence of arrhythmic events was often in the group with high RV TEI index. First, in cases with high RV TEI index, the presence of RV myocardial dysfunction may be obvious based on the evidence of decreased RVEF, lower tricuspid annular Sa velocity, and prolonged RVICT. The morphology of ventricular premature beats showed CLBBB pattern in this study, therefore the focus of premature beats was thought to be the RV. Thus, it is possible that the dysfunctioning RV may be the origin of a ventricular arrhythmia. Secondly, RA overloading due to RV dysfunction may induce myocardial damage of the atrium or intra-atrial conduction disturbance, which may be the origin of paroxysmal atrial fibrillation. Increased RA volume in the high RV TEI index group supports this speculation.

Clinical implications

In the present study, there was no patient with obvious signs of right heart failure in the high RV TEI index group. However, two patients have had frequent paroxysmal atrial fibrillation and have received antiarrhythmic and anticoagulant therapies. Careful follow-up seems to be necessary for the appearance of right heart failure or thromboembolic events in these patients. Prognostic significance of high RV TEI index is now unclear, and further study will be necessary to elucidate it.

Study limitation

There are some limitations in this study. First, the number of study patients is small, particularly in the high RV TEI index group. Further study will be necessary in a large number of patients with the high RV TEI index. The second limitation is in measuring the RV volume and the RVEF by using the apical four-chamber view. Correct measurement of the RV volume is thought to be difficult by means of echocardiographic methods because the RV shape is more complex than that of the left ventricle [21]. However, David et al. mentioned that the RVEF, determined by apical biplane echocardiography, correlated signifi-

cantly with that assessed by magnetic resonance imaging [18]. In addition, Bommer et al. described that two-dimensional echocardiography, with the apical four-chamber view, enables accurate visualization of the right ventricle in almost all patients by the study using human right-heart casts obtained at autopsy [22]. The purpose of this study is not to measure the RV volume and the RVEF correctly but to compare these values among the three study groups.

In conclusion, RV dysfunction or arrhythmic events may occur in some patients with CRBBB, and the RV TEI index may be useful for the detection and evaluation of these patients.

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