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Intraoperative Assessment of Left Ventricular Diastolic Function using Transesophageal Two-Dimensional Color Doppler Echocardiography during Coronary Artery Bypass Grafting

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Abstract

This study was designed to assess the usefulness of intraoperative measurement of left ventricular (LV) diastolic function by transesophageal Doppler echocardiography (TEE). Forty patients were studied, using a TEE probe (3.75 MHz) and an echocardiographic system (SSH-65A, Toshiba). Measurements were performed at: stage 1-after induction of anesthesia; stage 2-pre-cardiopulmonary-bypass (CPB) but before cannulation; stage 3-post-CPB after decannulation; and stage 4-following closure of the chest wall. Doppler-derived diastolic indices included:1) peak E velocity; 2) peak A velocity; 3) peak A/E ratio; 4) area A/E ratio; and 5) diastolic filling time (DFT).

In spite of our expectation for intraoparative application of Doppler-derived diastolic indices for monitoring LV diastolic function, our results showed the followings. Reliable measurements could no be performed mostly in stages 3 and 4: when temporary cardiac pacing was used or dysrhythmia was present in 13 of 40 patients (32.5 %) following CPB and when heart rate (HR) was higher than 90 beats·min^{-1} and fusion of E and A waves occurred in 12 of 40 patients (30.0 %) at the end of surgery. In addition, hemodynamics, especially HR, and surgical procedures such as opening of the chest, CPB, and revascularization, etc. each appeared to influence Doppler-derived diastolic indices in the different stages during surgery. The HR influenced Doppler-derived diastolic indices most significantly, particularly DFT ($r = -0.861$, $p < 0.001$).

The correlation between DFT and RR interval in both fused E-A waves group and normal E-A waves group showed that DFT was significantly shorter in the former than the latter with the same RR interval. This indicates the former may have a longer isovolumic relaxation time than the latter and this index seems to be useful for evaluating LV diastolic function during coronary artery bypass grafting.

Key Words: Coronary artery bypass grafting, Hemodynamics, Left ventricular diastolic function, Pulsed Doppler echocardiography, Transesophageal echocardiography

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Introduction

The importance of assessing left ventricular (LV) diastolic function has been reemphasized[1]. Abnormal LV diastolic function has been observed in patients with coronary artery disease (CAD), even though without systolic dysfunction[2-4]. In patients undergoing coronary artery bypass grafting (CABG), LV systolic function improves immediately after revascularization, accompanied by an increase in regional thickening[5]. However, the effect of CABG on LV diastolic function, in particular, intraoperative evaluation has not been fully clarified.

Transmitral flow pattern by pulsed wave Doppler echocardiography has been used to assess LV diastolic function[6-9]. Thus, the purpose of this study was to evaluate LV diastolic function and its influencing factors using transesophageal two-dimensional color Doppler echocardiography (TEE) during CABG.

Materials and Methods

Study Subjects

This study was approved by the Institutional Research Committee, and informed consent was obtained from all patients. We studied 40 patients scheduled for elective CABG who were without history of valvular disease or dysrhythmia (24 men and 16 women with a mean age of 61.9 ± 10.5 years, ranging from 41 to 84 years old).

Nineteen of those 40 patients had a previous history of myocardial infarction. Nineteen patients had ejection fractions over 50 %, 10 less than 50 %, and in the remaining 11, it was not available. One patient was classified as New York Heart Association class Ⅰ, 11 as class Ⅱ, 19 as class Ⅲ, and 9 as class Ⅳ. In addition, we examined 5 patients without any cardiac disease who underwent noncardiac surgery (gynecological, orthopedic, and general surgery) in supine position (mean age of 43.4±10.2 years).

Anesthetic Technique

Anesthesia was induced with a combination of intravenous administration of either midazolam (2-3 mg) or diazepam (5-10 mg) and sufentanil (1-2 $\mu g \cdot kg^{-1}$). Muscle relaxation was obtained with intravenous vecuronium (0.1-0.15$mg \cdot kg^{-1}$) or pancuronium (0.1-0.15$mg \cdot kg^{-1}$). Anesthesia was then maintained with sufentanil (total 5-8 $\mu g \cdot kg^{-1}$) and, if necessary, supplemented with isoflurane (less than 1.0 % in end-tidal concentration in 100 % oxygen). Patients who underwent noncardiac surgery were anesthetized by either sufentanil or isoflurane, with nitrous oxide and oxygen (50: 50).

Doppler Echocardiography

After induction of anesthesia and tracheal intubation, an endoscopic phased array probe (3.75 MHz, ESB-37LR, Toshiba, Tokyo, Japan) was inserted into the esophagus and attached to a color Doppler imaging system (SSH-65A, Toshiba). The probe tip was positioned at 30-35 cm from the incisors to obtain the long-axis view of the heart and adjusted to direct the ultrasonic beam as parallel to the transmitral flow as possible under the guidance of color flow mapping. The sample volume (width 2 mm) was placed at the midway between the tip of mitral leaflets and mitral annulus. An appropriate sampling position was confirmed with the auditory and spectral outputs. The pulse repetition frequency was 4 or 6 KHz.

Pulsed Doppler measurements of transmitral flow were performed at the following four stages: stage 1-after induction of anesthesia ; stage 2-pre-cardiopulmonary-bypass (CPB) but before cannulation ; stage 3-post-CPB after decannulation ; and stage 4-at the end of the operation following closure of the chest wall. Doppler data were recorded on a VHS video tape recorder (AG-6300, Panasonic, Osaka, Japan) with a simultaneous electrocardiographic recording (lead Ⅱ).

The following 5 Doppler-derived indices were measured: 1) peak velocity during early ventricular filling (peak E velocity); 2) peak velocity during atrial contraction (peak A velocity); 3) the ratio of peak A velocity to peak E velocity (peak A/E ratio); 4) the ratio of area above the Doppler velocity envelope during atrial filling to the area during early filling (area A/E ratio); 5) diastolic filling time (DFT). Doppler curves were traced along the modal velocity (the brightest portion of the velocity spectrum in the gray scales). RR interval was measured on the ECG tracing of the Doppler records. All measurements were performed during the expiratory phase and all calculations were done off-line on a computer. Three measurements were performed in each variable and the values were averaged. When the flow with atrial contraction began bofore the completion of the early rapid filling phase, the deceleration line of the velocity profile was extrapolated to the baseline to border between area A and area E[10].

In the 5 noncardiac patients, measurements were performed after induction of anesthesia but before skin incision.

Hemodynamics

Hemodynamic variables included: 1) heart rate (HR); 2) mean arterial pressure (MAP); 3) mean pulmonary capillary wedge pressure (PCWP); and 4) cardiac output (CO). Hemodynamic measurements were obtained simultaneously with Doppler recordings. Stroke volume (SV) was calculated from CO and HR.

Correlation coefficients between Doppler-derived indices and each hemodynamic data were examined in 110 study points and statistical significance was examined with t-test.

Results

Study points for data analysis

Study points in which patients needed cardiac pacing or had dysrhythmia were excluded from data analysis. This occurred in 1, 3, 13, and 9 patients at stages 1, 2, 3, and 4, respectively. When complete overlapping of the E and A peaks occurred, the data were not included because an accurate assessment could not be obtained. This occurred in 2, 10, and 12 patients at stages 2, 3, and 4, respectively.

Changes in Doppler-derived values and hemodynamic variables

Effect of chest opening: Data were compared

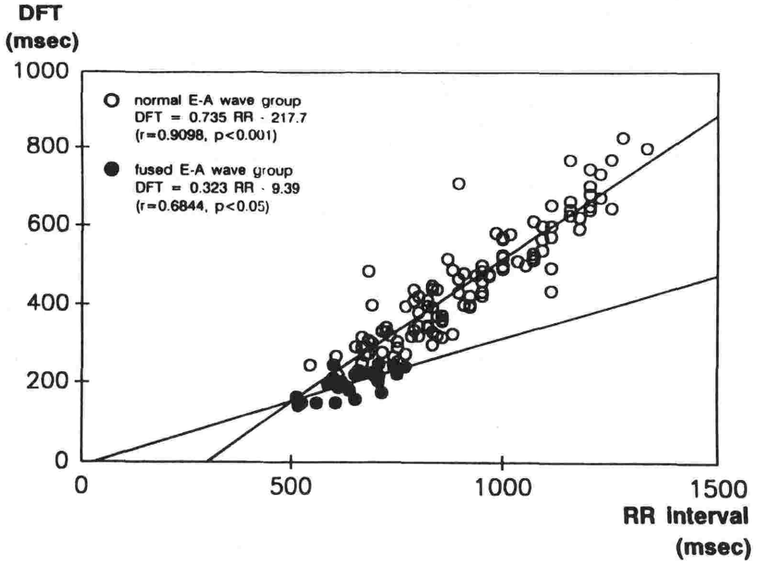

Fig. 1 Relationship between diastolic filling time (DFT) and RR interval in 1) normal E–A waves group (open circles; n = 110); and 2) fused E–A waves group (closed circles; n = 24).

between stage 1 and stage 2 in 34 patients using a paired t-test (Table 1). In stage 2, peak E velocity decreased ($p<0.005$), peak A/E ratio increased ($p<0.01$), and DFT was shortened ($p<0.005$). MAP, CO, and SV were reduced ($p<0.05$, $p<0.005$, and $p<0.001$, respectively), and HR increased ($p<0.01$).

Effect of CPB and revascularization: Data were compared between stages 2 and 3 in 15 patients (Table 2). In stage 3, peak E and peak A velocities increased ($p<0.05$ and $p<0.005$, respectively) and DFT decreased ($p<0.001$). CO and HR increased ($p<0.005$ and $p<0.001$, respectively) with no significant change in SV.

Effect of chest closure: Data were compared between stages 3 and 4 in 15 patients (Table 3). In stage 4, there was no significant change in Doppler-derived indices and hemodynamic

Table 1 Effect of chest opening on diastolic function (stage 1 to stage 2, n = 34)

	Stage 1	Stage 2	
Peak E velocity ($cm \cdot sec^{-1}$)	61.1±12.4	54.8±13.9	p<0.005
Peak A velocity ($cm \cdot sec^{-1}$)	54.7±15.3	56.2±14.9	NS
Peak A/E ratio	0.951±0.384	1.091±0.397	p<0.01
Area A/E ratio	0.429±0.133	0.465±0.167	NS
Diastolic filling time (msec)	554.4±130.4	488.3±131.4	p<0.005
RR interval (msec)	1038.3±153.2	958.8±164.9	p<0.01
Mean arterial pressure (mmHg)	77.7±12.8	72.1±12.5	p<0.05
PCWP (mmHg)	12.6±3.9	11.5±3.7	NS
Cardiac output ($l \cdot min^{-1}$)	4.56±1.11	4.04±0.79	p<0.005
Stroke volume (ml)	78.2±22.4	63.8±12.6	p<0.001
Heart rate ($beats \cdot min^{-1}$)	59.5±8.9	64.4±11.4	p<0.01

Values are mean ± standard deviation.
Peak E velocity = peak velocity during early ventricular filling ; Peak A velocity = peak velocity during atrial contraction ; Peak A/E ratio = the ratio of peak A velocity to peak E velocity ; Area A/E ratio = the ratio of area above Doppler velocity envelope during atrial filling to area during early filling ; PCWP = pulmonary capillary wedge pressure ; NS = not signficant.

Table 2 Effect of cardiopulmonary bypass and revascularization on diastolic function (stage 2 to stage 3, n = 15)

	Stage 2	Stage 3	
Peak E velocity ($cm \cdot sec^{-1}$)	52.3±16.3	59.4±13.2	p<0.05
Peak A velocity ($cm \cdot sec^{-1}$)	55.1±14.8	63.1±15.4	p<0.005
Peak A/E ratio	1.143±0.475	1.102±0.345	NS
Area A/E ratio	0.432±0.146	0.445±0.131	NS
Diastolic filling time (msec)	473.7±134.6	342.5±90.4	p<0.001
RR interval (msec)	947.5±166.1	746.3±73.7	p<0.001
Mean arterial pressure (mmHg)	74.3±12.7	70.9±9.0	NS
PCWP (mmHg)	12.8±4.3	12.7±3.9	NS
Cardiac output ($l \cdot min^{-1}$)	3.89±0.56	4.63±0.69	p<0.005
Stroke volume (ml)	61.0±11.7	57.3±7.5	NS
Heart rate ($beats \cdot min^{-1}$)	65.1±10.8	81.1±8.1	p<0.001

Values are mean ± standard deviation.
Peak E velocity = peak velocity during early ventricular filling ; Peak A velocity = peak velocity during atrial contraction ; Peak A/E ratio = the ratio of peak A velocity to peak E velocity ; Area A/E ratio = the ratio of area above Doppler velocity envelope during atrial filling to area during early filling ; PCWP = pulmonary capillary wedge pressure ; NS = not signficant.

variables except for an increase in PCWP ($p < 0.005$).

Changes between the beginning and the end of operation: Data were compared between stage 1 and stage 4 in 18 patients (Table 4). In stage 4, area A/E ratio increased ($p < 0.05$) and DFT decreased ($p<0.001$). HR and PCWP increased ($p < 0.001$ and $p < 0.05$, respectively) and SV decreased ($p<0.001$).

Relationship between Doppler-derived indices and hemodynamics

DFT was strongly correlated with HR ($r = -0.861$, $p < 0.001$). The correlation of HR with other Doppler-derived indices were significant but weak: peak A velocity ($r=0.373$, $p<0.001$); peak A/E ratio ($r=0.366$, $P<0.001$); and area A/E ratio ($r=0.195$, $p<0.05$). Peak A velocity, peak A/E ratio, and DFT were also weakly

Table 3 Effect of chest closure on diastolic function (stage 3 to stage 4, n = 15)

	Stage 3	Stage 4	
Peak E velocity (cm·sec^{-1})	59.6±14.9	57.1±14.0	NS
Peak A velocity (cm·sec^{-1})	63.2±15.1	59.3±14.3	NS
Peak A/E ratio	1.101±0.329	1.079±0.265	NS
Area A/E ratio	0.472±0.129	0.503±0.127	NS
Diastolic filling time (msec)	325.8±77.1	312.3±74.5	NS
RR interval (msec)	729.7±70.0	738.3±111.8	NS
Mean arterial pressure (mmHg)	70.7±9.6	74.4±11.3	NS
PCWP (mmHg)	12.4±4.1	15.1±4.1	p <0.005
Cardiac output (l·min^{-1})	4.68±0.80	4.44±1.27	NS
Stroke volume (ml)	56.3±7.6	53.5±11.7	NS
Heart rate (beats·min^{-1})	82.9±7.9	83.1±12.8	NS

Values are mean ± standard deviation.
Peak E velocity = peak velocity during early ventricular filling ; Peak A velocity = peak velocity during atrial contraction ; Peak A/E ratio = the ratio of peak A velocity to peak E velocity ; Area A/E ratio = the ratio of area above Doppler velocity envelope during atrial filling to area during early filling ; PCWP = pulmonary capillary wedge pressure ; NS = not signficant.

Table 4 Effect of surgery on diastolic function (stage 1 to stage 4, n = 18)

	Stage 1	Stage 4	
Peak E velocity (cm·sec^{-1})	60.5±13.4	56.4±13.2	NS
Peak A velocity (cm·sec^{-1})	54.1±16.2	57.8±14.3	NS
Peak A/E ratio	0.971±0.459	1.056±0.248	NS
Area A/E ratio	0.431±0.139	0.498±0.137	p <0.05
Diastolic filling time (msec)	522.9±148.5	317.7±69.7	p <0.001
RR interval (msec)	1007.7±165.8	751.4±107.7	p <0.001
Mean arterial pressure (mmHg)	76.8±16.0	75.1±10.6	NS
PCWP (mmHg)	12.8±3.7	14.9±3.8	p <0.05
Cardiac output (l·min^{-1})	4.32±0.85	4.42±1.16	NS
Stroke-volume (ml)	72.0±15.8	54.4±10.9	p <0.001
Heart rate (beats·min^{-1})	61.1±9.9	81.5±12.3	p <0.001

Values are mean ± standard deviation.
Peak E velocity = peak velocity during early ventricular filling ; Peak A velocity = peak velocity during atrial contraction ; Peak A/E ratio = the ratio of peak A velocity to peak E velocity ; Area A/E ratio = the ratio of area above Doppler velocity envelope during atrial filling to area during early filling ; PCWP = pulmonary capillary wedge pressure ; NS = not signficant.

correlated with SV ($r = -0.211$, $p < 0.05$; $r = -0.295$, $p < 0.002$, ; and $r = 0.529$, $p < 0.001$, respectively). There was no significant correlation between any Doppler-derived indices and MAP, PCWP, and CO.

Relationship between DFT and RR interval

Figure 1 shows the relationship between DFT and RR interval in 1) normal E-A waves group (open circles; $n = 110$); and 2) fused E-A waves group (closed circles; $n = 24$). DFT was strongly correlated with RR interval ($r = 0.9098$, $P < 0.001$) in normal E-A waves group and weakly correlated in fused E-A waves group ($r = 0.6844$, $p < 0.05$). The slope of the regression line in fused E-A waves group was significantly smaller than that in normal E-A waves group ($p < 0.001$), as reported before[11].

In addition, 10 study points were selected from the normal E-A waves group-RR interval matched to the fused E-A waves group, and DFT between those two groups were compared. DFT in these study points was significantly longer than that of the fused group (262.6±38.4 msec versus 199.4±34.6 msec, $p < 0.001$).

Comparison between the control ($n = 5$) and CABG group ($n = 39$) for Doppler-derived indices and hemodynamic data in stage 1

DFT was longer and HR was lower in CABG patients (531.7 ± 136.6 msec versus 336.6 ± 111.9 msec, $p < 0.001$ and 60.4±8.9 beats·min^{-1} versus 80.0 ± 17.5 beats·min^{-1}, $p < 0.05$, respectively). Because Doppler-derived indices have been reported to be affected by the age of subjects[12,13], we selected 12 patients from CABG patients, age-matched to control patients (51.2±6.2 years old versus 43.4±10.2 years old, NS), and Doppler-derived data were again compared between these two groups. In CABG patients, DFT was again significantly longer (543.4 ± 139.3 msec versus 336.6±111.9 msec, $P < 0.01$) and HR was significantly lower (59.8 ± 9.1 beats·min^{-1} versus 80.0±17.5 beats·min^{-1}, $p < 0.05$). However, other indices did not show any significant differences.

Discussion

Recent studies by Doppler echocardiography demonstrated an abnormal LV relaxation as a decease in peak E velocity and an increase in peak A velocity in patients with CAD[14-17]. In our study, we did not find any significant difference in diastolic indices between CABG and noncardiac surgical patients, except for significantly longer DFT in CABG patients. Abnormalities of diastolic function are reported to appear early in myocardial ischemia[18], and are considered to be an excellent monitor for early detection of myocardial ischemia in patients with CAD.

It is, however, controversial whether the diastolic function is useful in evaluating an improvement of myocardial ischemia in patients undergoing CABG. Humphrey et al. demonstrated an immediate enhancement of LV relaxation after CABG using the time constant of isovolumetric relaxation[19]. Lawson et al. demonstrated that it took one week to normalize the LV diastolic dysfunction after successful CABG[16]. Wehlage et al. even observed a deterioration in LV filling pattern after CABG by the intraoperative Doppler study[20]. In our study, there were no changes in E and A wave patterns at the end of operation compared with those at the beginning.

In spite of our expectation for application of Doppler-derived indices for monitoring LV diastolic function during CABG, we observed several problems.

1. Factors that influence measurements of LV diastolic function are 1) age[12,13] ; and 2) hemodynamic conditions, such as preload, afterload, contractility, and HR[21-25]. Our study demonstrated that peak A velocity, peak A/E ratio, and area A/E ratio were correlated significantly but weakly with age ($r = 0.394$, 0.348, and 0.393, $p < 0.001$, respectively). DFT was strongly correlated with HR, and other Doppler-derived indices had a weak correlation

with HR. Peak A velocity, peak A/E ratio, DFT were significantly correlated with SV, possibly through the effect of HR. It is not clear whether these extrinsic factors or an intrinsic abnormality of relaxation has greater effects on Doppler-derived indices. A combined hemo-dynamic and Doppler echocardiographic study by Appleton et al. suggested that the mitral flow patterns were related more to hemodynamic conditions than to the type of diseases itself such as CAD and idiopathic congestive cardiomyopathy[26). On the other hand, Diver et al.[27) showed that the impairment of diastolic function in patients with aortic stenosis remained unchanged even when LV pressure was reduced to normal. This suggested that an intrinsic abnormality of relaxation might be the dominating cause.

2. Sternotomy and pericardiotomy affected both hemodynamics and Doppler-derived indices; peak E velocity and DFT decreased; MAP and CO decreased; and HR increased.

3. Reliable measurements cannot be performed when temporary cardiac pacing is used or dysrhythmia is present during CABG surgery. This occurred in 32.5 % (13/40) of the patients in stage 3 and in 22.5 % (9/40) of the patients in stage 4. When HR was higher than 90 beats・min^{-1}, complete overlapping of E and A waves occurred frequently and the Doppler measurements were not feasible ($p < 0.005$, chi-square test, Table 5). This occurred in 25.0 % (10/40) of patients in stage 3 and 30.0 % (12/40) of patients in stage 4. HR was significantly higher in fused E-A waves group compared with normal E-A waves group (94.9 ± 11.2 versus 81.2 ± 10.8 beats・min^{-1}, $p<0.001$).

However, threshold of HR for fusion seemed to be different among individuals. No overlapping occurred with HR over 95 beats・min^{-1} in 3 patients. Our results showed that DFT was significantly shorter in the fused E-A group than in the normal E-A waves group with the same RR interval. This appears to indicate that the former group may have a longer isovolumic relaxation time than the latter group, and this index can be useful in evaluating diastolic function. Further study is necessary to determine its mechanism and clinical significance.

In conclusion, TEE is the only nonivasive modality for evaluating LV diastolic function during CABG surgery. However, interpretation of Doppler-derived data is not simple because: 1) these indices are influenced by several factors, including age, hemodynamic condition, and surgical intervention; and 2) measurements are not consistently available. Further study is necessary for a reliable intraoperative evaluation of LV diastolic function with Doppler measurements.

Acknowledgment: The authors express their appreciation to Dr. Edward L. Yellin, Professor of Surgery & Biophysics, Albert Einstein College of Medicine, for his expert suggestion for this study.

Table 5 Relationship between heart rate and overlapping of E and A waves in stages 3 and 4

	Overlapping (−)	Overlapping (+)
Number of patients with heart rate		
≦ 89 (beats・min^{-1})	28	8
≧ 90 (beats・min^{-1})	8	14*
Heart rate (beats・min^{-1}) mean ± standard deviation	81.2±10.8	94.9±11.2**

*$p < 0.005$ by chi−square test.
**$p < 0.001$ by t−test.

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