

Originals

Hemodynamic Effects of Positive end - expiratory Pressure on Right Ventricular Diastolic Function in Patients with Acute Myocardial Infarction

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SUMMARY

The effects of positive end - expiratory pressure (PEEP) on the right ventricular (RV) diastolic function in patients with congestive heart failure (CHF) due to acute myocardial infarction (AMI) are unknown. The aim in this study was to investigate PEEP associated variations in RV diastolic function in CHF due to AMI. The subjects comprised the control group (26 subjects) and the AMI group (36 subjects) classified as 20 patients with pulmonary capillary wedge pressure (PCWP) < 18 mmHg (CHF - low PCWP group) and 16 patients with PCWP \geq 18 mmHg (CHF - high PCWP group). PEEP was applied for 30 minutes at 0, 5, 10 and 15 cmH₂O. Two - dimensional echocardiography with continuous and pulse wave Doppler studies was performed. RV diastolic functional parameters included the ratio of peak early tricuspid valve filling and peak atrial filling velocities, the deceleration time of the tricuspid E valve and the RV isovolumic relaxation time. In the control and CHF - low PCWP groups, right atrial pressure, mean pulmonary arterial pressure (mPAP), total pulmonary resistance (TPR) and systemic vascular resistance (SVR) increased, output (CO) decreased and RV diastolic functional parameters worsened significantly at the transition from 10 to 15 cmH₂O PEEP. In the CHF - high PCWP group, mPAP, TPR and SVR decreased, while CO increased and RV diastolic functional parameters improved significantly at the transition from 10 to 15 cmH₂O PEEP. From these findings, it is clear that PEEP induced hemodynamic deterioration and reduces RV diastolic function in intact and mildly failing hearts. On the other hand, in severely failing hearts, PEEP offers hemodynamic improvement and ameliorates RV diastolic function. It appears possible to predict responses to PEEP by determining RV diastolic function in CHF. Therefore, we conclude that evaluation of the RV diastolic function during PEEP is highly important in terms of recognizing the effectiveness of PEEP therapy in CHF.

Key Words : diastole, congestive heart failure, right ventricle, PEEP

INTRODUCTION

It is known that positive end - expiratory pressure

(PEEP) greatly affects right - heart hemodynamics^{1, 2)} which are notoriously difficult to ascertain because they are heavily influenced by right ventricular (RV) volume and right atrial pressure (RAP)³⁾. It is also known that the effects are variable in patients with heart failure and are dependent upon the underlying pathology⁴⁾. PEEP that is applied for left ventricular (LV) failure acts to increase the oxygenation of arterial blood and to decrease

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both pulmonary alveolar edema and pulmonary interstitial edema. Furthermore, an increase in the intrathoracic pressure results in an increase in the LV preload and a decrease in the LV afterload. These changes combine to improve LV function⁵⁾. Nevertheless, it is reported that in the right heart, PEEP causes a decrease in the venous return to the right atrium by increasing intrathoracic pressure as well as increasing the RV afterload, which results from a rise in the pulmonary resistance and thus induced a lowered RV ejection function^{6, 7)}. Yu et al. reported recently on the complication of RV diastolic dysfunction in patients with LV failure⁸⁾. Further, Grace and Greenbaum⁵⁾, in a study that examined these issues with particular attention to left atrial pressure, produced results that indicated different responses to PEEP according to the severity of heart failure.

Acute myocardial infarction (AMI) is the most common disease resulting in LV failure. In patients with AMI, evaluation of pulmonary capillary wedge pressure (PCWP) provides an assessment of hemodynamic severity⁹⁾. The effects of PEEP on RV diastolic function in patients with congestive heart failure (CHF) due to AMI are unknown. We examined the effects of PEEP on RV diastolic function in patients with CHF due to AMI and classified the severity of heart failure by the PCWP values.

SUBJECTS AND METHODS

1. Subjects

The subjects were 62 patients admitted to the Intensive Care Unit (ICU) of the Dokkyo University School of Medicine for control of hemodynamics and respiration, between June, 1999 and February, 2002. Details of the subjects are shown in Table 1. All patients in the control group were admitted to the ICU for operation for gastrointestinal disease. The AMI group was further classified into 20 subjects whose PCWP was less than 18 mmHg (CHF - low PCWP group) and 16 patients whose PCWP was equal to or greater than 18 mmHg (CHF - high PCWP group). All AMI cases were anteroseptal infarction without cardiogenic shock. Anteroseptal infarction criteria included prolonged chest pain (> 30 min), an electrocardiographic ST segment elevation > 2 mV in two or more adjacent precordial leads and more than a three-fold increase in serum creatine phosphokinase levels. For all patients with AMI, Arterial oxygen partial pressure

(PaO₂) was less than 50 torr and arterial blood carbon dioxide partial pressure (PaCO₂) was between 50 and 60 torr in room air when they were admitted to the ICU and the concentration of inhaled oxygen was 60 torr (FiO₂ 1.0). Thus all required mechanical ventilatory support. In all patients, maximum airway pressure when they were attached to a respirator was not more than 35 cm H₂O. For the control group, medication was interrupted at least 48 hours before the test. All patients with AMI had been treated with diuretics, nitrates and heparin; and there was no difference between the CHF - low and CHF - high PCWP group in their dosages. No catecholamines had been given to any of the patients.

To meet the strict ethical requirements for measuring hemodynamic parameters with the aid of right cardiac catheterization while under the effect of PEEP, the purpose of the present study and a detailed explanation of the test was given to all individuals in the control group and their families. Consent was obtained the day before surgery. The same explanations were given to the families of the AMI patients and their consent was likewise obtained.

On the day of surgery, PEEP was performed on the control group in increasing increments under intravenous anesthesia and to the AMI group under sustained intravenous infusion of 3-5 mg/hour of midazolam. At each stage, various hemodynamic parameters were determined by right cardiac catheterization with an echocardiographic examination and blood gas analysis.

2. Methods

1) Respirator used and PEEP setting

A respirator (Bennett 7200 ae, Carebat, CA, USA) was connected to a tube inserted in the respiratory tract in all patients and PEEP ventilation was initiated. The gas exchange condition was 1.0 for the fraction of inspired oxygen (FiO₂) and the exchange frequency was 12/minute. The volume of each gas exchange was adjusted so as to keep PaCO₂ between 30 and 40 mmHg. PEEP was applied for 30 minutes at 0, 5, 10 and 15 cm H₂O.

2) Doppler echocardiographic method

Doppler echocardiographic equipment (Sequoia C256, 50793, Acuson Co. CA, USA) was used. LVEF was measured by the M - mode and 2 - dimensional Simpson's method. Two - dimensional echocardiography with continuous and pulse wave Doppler studies was performed. RV

diastolic function was assessed with the parasternal short-axis view at the level of the tricuspid valve (TV) and the sampling window placed at the tricuspid annulus; enabling tricuspid in-flow velocities to be recorded. Diastolic parameters were measured for at least five beats. These parameters included peak early tricuspid valve filling velocity (E wave), peak atrial filling velocity (A wave), the ratio of these velocity waves (TV-E/A) and the deceleration time of the tricuspid E wave (TV-DcT). The RV isovolumic relaxation time (RV-IRT) was defined as the time interval between the closure of the pulmonary valve and opening of the TV. This was estimated by subtracting the time interval between the peak of the R wave on the ECG and the onset of TV opening from the interval between the peak of the R wave and the end of the pulmonary systolic flow profile. Doppler echocardiography tests were performed at PEEP settings of 0, 5, 10 and 15 cm H₂O by two experienced doctors. The doctors performed tests independently while blinded to the PEEP levels; each using the mean of 5 successive heartbeats; the two means were averaged and used as the reported value.

3) Hemodynamic measurements

In all patients in the control and AMI groups, a Swan-Ganz CCO thermodilution catheter (7.5 Fr., Baxter, Westmidvale, Utah, U.S.A.) was inserted through either the right femoral or the right internal jugular vein. Heart rate (HR: beats/min), pulmonary arterial pressure (PAP), and central venous pressure (CVP) were measured via a pressure transducer (A287, Cobe, Lakewood, CO, U.S.A.) and with a monitoring system (Bedside monitor DS-5300, Fukuda Electronics, Tokyo, JAPAN). Arterial pressure was measured by inserting a radifocus catheter (8 Fr., Terumo, Tokyo, Japan) into the right femoral artery. Cardiac output (CO) was determined by the thermodilution technique with 10 ml of cold (0 °C) 5% dextrose solution. The recorded CO was the mean of three determinations performed at each level of PEEP. Each parameter was continuously recorded. Systemic vascular resistance (SVR) and total pulmonary resistance (TPR) were computed with the following equations:

$$\text{SVR (dyne} \cdot \text{sec} \cdot \text{cm}^{-5}) = \text{mBP} - \text{mRA} / \text{CO} \times 80$$

$$\text{TPR (dyne} \cdot \text{sec} \cdot \text{cm}^{-5}) = \text{mPA} / \text{CO} \times 80$$

where mBP = mean blood pressure, mRA = mean

right atrial pressure and mPA = mean pulmonary arterial pressure.

4) Arterial blood - gas measurement

Arterial blood was collected from the catheter in the right femoral artery and gas analysis was performed with an OMNI9 (Avl List GmbH Mdezechnik, Graz, Austria). PaO₂ and PaCO₂ were measured.

3. Statistical analysis :

Comparisons of baseline data among the three groups were carried out by analysis of variance (Statview 4.0, Abacus concept, Ardsley, CA, USA). Hemodynamic variables were compared within each of the three groups at baseline. In order to examine relationships between baseline RV diastolic parameters and TPR, the change in each RV diastolic parameter from baseline to 5, 10 and 15 cm H₂O of PEEP were regressed against baseline PCWP by the paired t test. Data were expressed as means \pm standard deviation. A P-value of < 0.05 was considered to be statistically significant.

RESULTS

1. Patient background

As Table 1 sets out, there were no significant age differences among the 3 groups. However, PaO₂ in the CHF-high PCWP group was significantly lower than in the control group (175 \pm 89 vs 429 \pm 41 mmHg, $p < 0.05$) when FiO₂ was 1.0 and PEEP was 0 cm H₂O. LVEF was higher in the control group than in the CHF-low PCWP or CHF-high PCWP groups, but LVEF in the high PCWP group was lowest (24 \pm 9%). Compared with the control group, the PCWP value was high in both the CHF-low and CHF-high PCWP groups (5.4 \pm 1.1 vs 12.8 \pm 2.4 mmHg, $p < 0.05$; 5.4 \pm 1.1 vs 19.1 \pm 1.0 mmHg, $p < 0.01$). No difference was noted in HR among the 3 groups.

As Table 2 shows, significant differences in TV-E/A were found between the control and the CHF-low PCWP group (1.2 \pm 0.1 vs 0.9 \pm 0.4, $p < 0.05$), and between the control and the CHF-high PCWP group (1.2 \pm 0.1 vs 0.7 \pm 0.2, $p < 0.01$). TV-DcT showed no significant difference between the CHF-low PCWP and the control groups (172 \pm 5.2 vs 169 \pm 6.3 ms, ns); however, it was significantly shorter in the CHF-high PCWP group than in the control (117 \pm 2.3 vs 169 \pm 6.3 ms, $p < 0.01$). RV-IRT was significantly longer in both CHF-low PCWP

Table 1 Characteristics of control and CHF groups

Group	Age years	M : F	LVEF %	PCWP mmHg	CO l/min	HR beats/min	PaO ₂ mmHg
Control (n = 26)	61 ± 11	18 : 8	62 ± 15	5.4 ± 1.1	5.1 ± 1.2	86 ± 69.3	429 ± 41
CHF low - PCWP (n = 20)	58 ± 12	12 : 8	34 ± 19*	12.8 ± 2.4*	4.8 ± 1.1	84 ± 8.4	263 ± 116
CHF high - PCWP (n = 16)	62 ± 11	10 : 6	24 ± 9**	19.1 ± 1.0**	3.8 ± 0.5**	96 ± 9.2	175 ± 89*

Data shown are means ± SD.

PCWP = pulmonary capillary wedge pressure.

CHF high - PCWP group = pulmonary capillary wedge pressure ≥ 18 mmHg.

CHF low - PCWP group = pulmonary capillary wedge pressure < 18 mmHg.

LVEF = left ventricular ejection fraction. PaO₂ = arterial oxygen partial pressure.

* = p < 0.05 vs control. ** = p < 0.01 vs control.

Table 2 Right ventricular diastolic parameters in control and CHF groups (FiO₂ 1.0, PEEP 0 cmH₂O)

	control (n = 26)	CHF - low PCWP (n = 20)	CHF - high PCWP (n = 16)
TV - E/A	1.2 ± 0.1	0.9 ± 0.4*	0.7 ± 0.2**
TV - DcT (ms)	169 ± 6.3	172 ± 5.2	117 ± 2.3**
RV - IRT (ms)	59 ± 4.1	79 ± 4.7*	92 ± 16**

Data shown are means ± SD.

CHF = congestive heart failure. TV - E/A = ratio of peak transtricuspid E - wave velocity to peak transtricuspid A - wave velocity. TV - DcT = deceleration time of transtricuspid E wave. RV - IRT = right ventricular isovolumic relaxation time. CHF low - PCWP group = pulmonary capillary wedge pressure < 18 mmHg. CHF - high PCWP group = pulmonary capillary wedge pressure ≥ 18 mmHg. * = p < 0.05 vs control. ** = p < 0.01 vs control.

and CHF - high PCWP groups than in the control (79 ± 4.7 vs 59 ± 4.1 ms, 92 ± 16 vs 59 ± 4.1 ms, p < 0.05 in both cases).

2. Correlation between TPR and RV diastolic functional parameters (Fig. 1)

The correlations between TPR and RV diastolic functional parameters were examined in all patients when FiO₂ was 1.0 and PEEP was 0 cm H₂O. TPR correlate significantly with TV - E/A and TV - E/A and TV - DcT (r = -0.78, r = -0.80, p < 0.0001). A positive significant correlation was found between TPR and RV - IRT (r = 0.84, p < 0.0001).

3. Effects of PEEP in hemodynamics and arterial blood - gas evaluation in the control, CHF - low PCWP and CHF - high PCWP groups (Tables 3, 4, 5)

As seen from Table 3, in the control group, mPAP, RAP, TPR and SVR rose significantly from PEEP at 0 cm H₂O to

PEEP at 10 and 15 cm H₂O. No significant change occurred in mBP. CO decreased significantly when PEEP was 10 or 15 cm H₂O from when PEEP was 0 cm H₂O.

As shown in Table 4, in the CHF - low PCWP group, mPAP, RAP, TPR and SVR increased significantly from PEEP at 0 cm H₂O to PEEP at 10 or 15 cm H₂O. CO decreased significantly when PEEP was 10 or 15 cmH₂O from when PEEP was 0 cm H₂O.

Table 5 shows that in the CHF - high PCWP group, RAP rose significantly from PEEP at 0 cm H₂O to 15 cm H₂O but, mPAP, TPR and SVR decreased significantly from PEEP at 0 cm H₂O to 10 or 15 cm H₂O. CO increased significantly from PEEP at 0 cm H₂O to PEEP at 10 or 15 cm H₂O. No significant changes occurred in HR or PaCO₂ in the three groups.

4. Changes in RV diastolic parameters caused by PEEP in the control, CHF - low PCWP and CHF - high PCWP groups (Fig. 2)

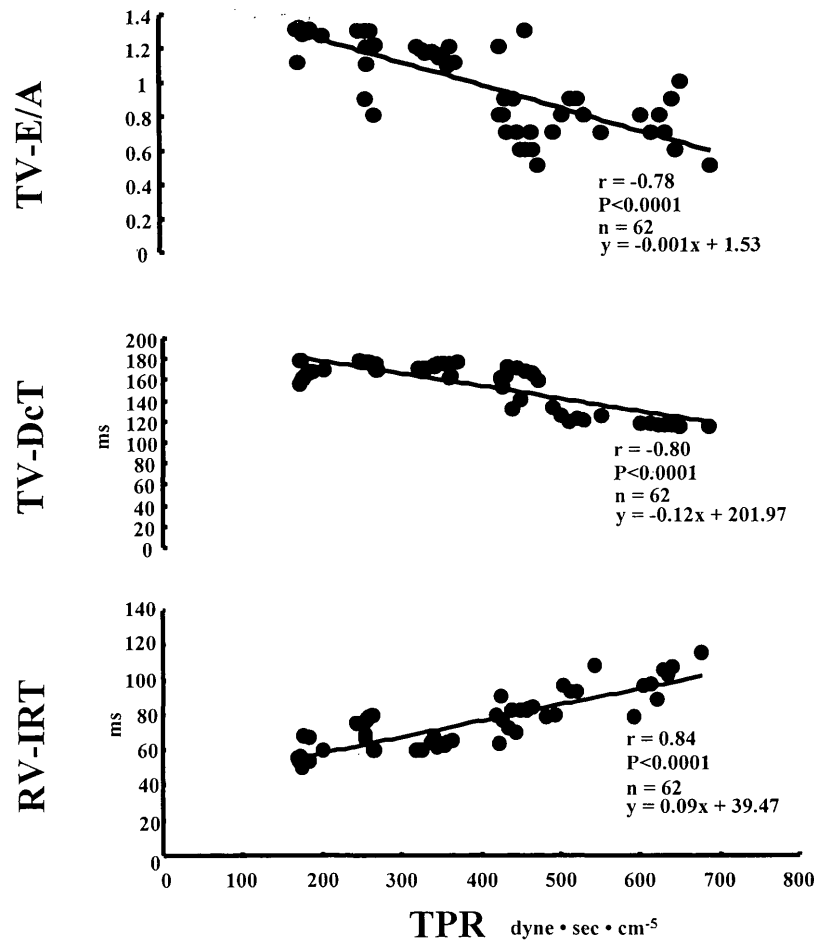


Fig. 1 Correlation between TPR and RV diastolic functional parameters

Correlations between TPR and RV diastolic functional parameters were examined in all patients when FiO_2 was 1.0 and PEEP was 0 $\text{cm H}_2\text{O}$. Negative correlations were found between TPR and TV - E/A ($r = -0.78$, $P < 0.0001$, $n = 62$) and between TPR and TV - DcT ($r = -0.80$, $p < 0.0001$, $n = 62$). A positive significant correlation was found between TPR and RV - IRT ($r = 0.84$, $p < 0.0001$, $n = 62$).

Table 3 Effects of PEEP on hemodynamic parameters and gas exchange in control group ($n = 26$)

PEEP (cmH_2O)	0	5	10	15
HR (beats/min)	82 ± 5	82 ± 3	80 ± 5	81 ± 4
mBP (mmHg)	86 ± 7	85 ± 3	85 ± 5	84 ± 5
mPAP (mmHg)	16 ± 3	18 ± 6	$19 \pm 3^*$	$21 \pm 3^{**}$
RAP (mmHg)	$4.30 \pm .8$	6.8 ± 1	$7.3 \pm 0.8^*$	$8.9 \pm 0.9^{**}$
TPR ($\text{dyne} \cdot \text{sec} \cdot \text{cm}^{-5}$)	268 ± 98	345 ± 102	$386 \pm 66^*$	$467 \pm 89^{**}$
SVR ($\text{dyne} \cdot \text{sec} \cdot \text{cm}^{-5}$)	1334 ± 296	1509 ± 200	$1874 \pm 363^*$	$2002 \pm 328^{**}$
CO (l/min)	4.9 ± 1	4.2 ± 0.8	$4.0 \pm 1.2^*$	$3.6 \pm 1.0^{**}$
PaO_2 (mmHg)	283 ± 99	296 ± 104	$327 \pm 58^*$	$398 \pm 60^{**}$
PaCO_2 (mmHg)	37 ± 3.8	38 ± 4	37 ± 4	38 ± 4.3

Data shown are means \pm SD. * = $P < 0.05$ vs PEEP 0 mmHg. ** = $p < 0.01$ vs PEEP 0 mmHg.

PEEP = positive end - expiratory pressure. HR = heart rate. mBP = mean blood pressure. mPAP = mean pulmonary arterial pressure. RAP = right atrial pressure. TPR = total pulmonary resistance. SVR = systemic vascular resistance. CO = cardiac output. PaO_2 = arterial oxygen partial pressure. PaCO_2 = arterial carbonic dioxide partial pressure.

Table 4 Effects of PEEP on hemodynamic parameters and gas exchange in CHF -low PCWP group (n = 20)

PEEP (cmH ₂ O)	0	5	10	15
HR (beats/min)	79 ± 3	80 ± 4	81 ± 5	80 ± 6
mBP (mmHg)	83 ± 6	81 ± 6	89 ± 7 *	99 ± 4 **
mPAP (mmHg)	21 ± 6	22 ± 6.3	24 ± 3.2 *	24 ± 4 *
RAP (mmHg)	7.6 ± 2.5	9.4 ± 2.9	11 ± 2.5 *	12 ± 2.8 **
TPR (dyne · sec · cm ⁻⁵)	357 ± 96	425 ± 125	492 ± 99 *	551 ± 104 **
SVR (dyne · sec · cm ⁻⁵)	1267 ± 255	1397 ± 276	1627 ± 327 *	1881 ± 107 **
CO (l/min)	4.8 ± 1.1	4.1 ± 0.9	3.9 ± 1.1 *	3.7 ± 0.9 *
PaO ₂ (mmHg)	263 ± 109	287 ± 124	305 ± 68 *	337 ± 88 **
PaCO ₂ (mmHg)	39 ± 3.2	37 ± 4	37 ± 4.7	38 ± 4.3

Data shown are means ± SD. * = P < 0.05 vs PEEP 0 mmHg. ** = p < 0.01 vs PEEP 0 mmHg.

PEEP = positive end - expiratory pressure. HR = heart rate. mBP = mean blood pressure. mPAP = mean pulmonary arterial pressure. RAP = right atrial pressure. TPR = total pulmonary resistance. SVR = systemic vascular resistance. CO = cardiac output. PaO₂ = arterial oxygen partial pressure. PaCO₂ = arterial carbonic dioxide partial pressure.

Table 5 Effects of PEEP on hemodynamic parameters and gas exchange in CHF -high PCWP group (n = 16)

PEEP (cmH ₂ O)	0	5	10	15
HR (beats/min)	96 ± 4.5	95 ± 4	92 ± 4.1	92 ± 4.6
mBP (mmHg)	79 ± 17	79 ± 16	70 ± 7 *	75 ± 6 *
mPAP (mmHg)	27 ± 4.3	25 ± 1.9	22 ± 2.6 *	22 ± 1.7 *
RAP (mmHg)	9 ± 2.5	9.7 ± 2.7	10 ± 1.7 *	12 ± 1.9 *
TPR (dyne · sec · cm ⁻⁵)	560 ± 97	531 ± 89	409 ± 90 *	406 ± 88 *
SVR (dyne · sec · cm ⁻⁵)	1476 ± 430	1461 ± 442	1125 ± 304 *	1067 ± 254 **
CO (l/min)	3.8 ± 0.5	3.8 ± 0.6	4.3 ± 0.6 *	4.3 ± 0.5 *
PaO ₂ (mmHg)	185 ± 84	234 ± 104	291 ± 78 *	318 ± 87 *
PaCO ₂ (mmHg)	36 ± 6.2	35 ± 5.4	34 ± 4.6	36 ± 4.3

Data shown are means ± SD. * = P < 0.05 vs PEEP 0 mmHg. ** = p < 0.01 vs PEEP 0 mmHg.

PEEP = positive end - expiratory pressure. E/A = E - A ratio. DcT = deceleration time of tricuspid E wave. IRT = isovolumic relaxation time. HR = heart rate. mBP = mean blood pressure. mPAP = mean pulmonary arterial pressure. RAP = right atrial pressure. TPR = total pulmonary resistance. SVR = systemic vascular resistance. CO = cardiac output. PaO₂ = arterial oxygen partial pressure. PaCO₂ = arterial carbonic dioxide partial pressure.

Fig. 2 (A) shows that in the control and CHF -low PCWP groups, TV -E/A decreased significantly from PEEP at 0 cm H₂O to PEEP at 10 or 15 cm H₂O but in the CHF -high PCWP group, TV -E/A increased significantly from PEEP at 0 cm H₂O to PEEP at 10 or 15 cm H₂O.

Fig. 2 (B) shows that in the control and CHF -low PCWP groups, TV -DcT decreased significantly from PEEP at 0 cm H₂O to PEEP at 10 or 15 cm H₂O but in the CHF -high PCWP group, TV -DcT increased significantly from PEEP at 0 cm H₂O to PEEP at 10 or 15 cm H₂O.

Fig. 2 (C) shows that in the control and CHF -low PCWP groups, RV -IRT was significantly prolonged from PEEP at 0 cm H₂O to PEEP at 10 or 15 cm H₂O, whereas in the CHF -high PCWP group, RV -IRT was significantly from PEEP at 0 cm H₂O to PEEP at 10 or 15 cm H₂O.

DISCUSSION

We examined RV diastolic function in 62 patients by means of Doppler echocardiography. In the present study, all protocols were successfully completed for all

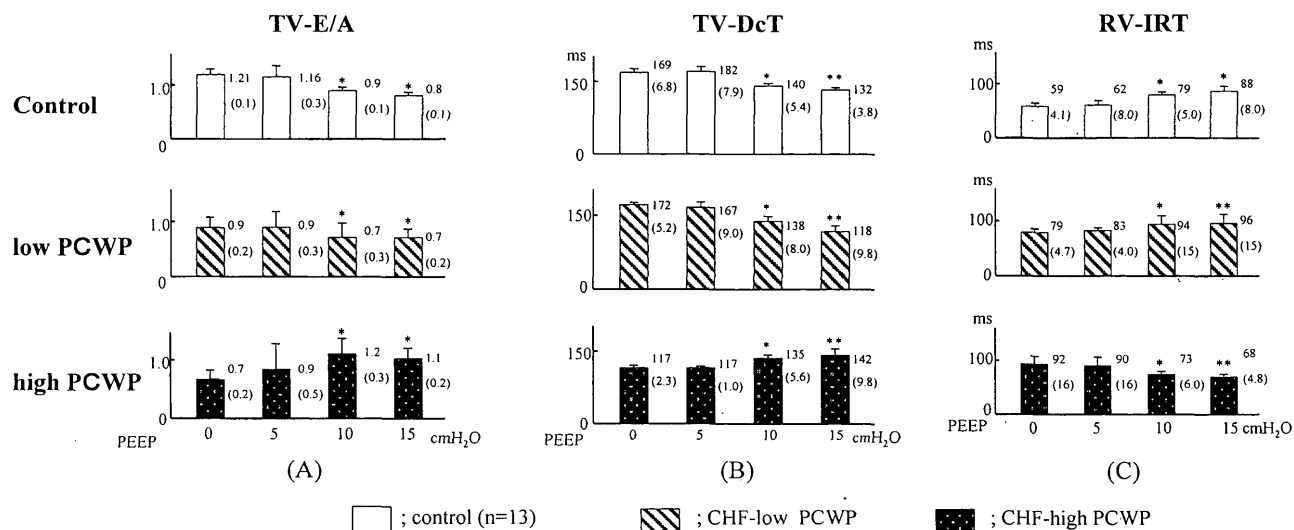


Fig. 2 TV - E/A, TV - DcT and RV - IRT response to PEEP of 5, 10 and 15 cm H₂O in the control, CHF - low PCWP and CHF - high PCWP groups.

(A) TV - E/A response to PEEP

Note the decremental reductions in TV - E/A among the control groups with increasing PEEP from 0 cm H₂O to 10 and 15 cm H₂O (from 1.21 ± 0.1 to 0.9 ± 0.1 to 0.8 ± 0.1). Similar results were observed in the CHF - low PCWP group (from 0.9 ± 0.2 to 0.7 ± 0.3 to 0.7 ± 0.2). In contrast, the CHF - high PCWP group showed an incremental increase in TV - E/A with increasing PEEP from 0 cm H₂O to 10 and 15 cm H₂O (from 0.7 ± 0.2 to 1.2 ± 0.3 to 1.1 ± 0.2). * = $P < 0.05$ vs PEEP 0 cm H₂O.

(B) TV - DcT response to PEEP

Note the decremental shortness in TV - DcT among the control group with increasing PEEP from 0 cm H₂O to 10 and 15 cm H₂O (from 169 ± 6.8 to 140 ± 5.4 to 132 ± 3.8 ms). Similar results were observed in the CHF - low PCWP group (from 172 ± 5.2 to 138 ± 8.0 to 118 ± 9.8 ms). In contrast, the CHF - high PCWP group experienced a gradual prolongation in TV - DcT with increasing PEEP from 0 cm H₂O to 10 and 15 cm H₂O (from 117 ± 2.3 to 135 ± 5.6 to 142 ± 9.8 ms). * = $P < 0.05$ vs PEEP at 0 cm H₂O. ** = $P < 0.01$ vs PEEP at 0 cm H₂O.

(C) RV - IRT response to PEEP

In the control group, there was a significant prolongation in RV - IRT with increasing PEEP from 0 cm H₂O to 10 and 15 cm H₂O (from 59 ± 4.1 to 79 ± 5.0 to 88 ± 8.0 ms). The same was true of the CHF - low PCWP group (from 79 ± 4.7 to 94 ± 15 to 96 ± 15 ms). Nevertheless, the opposite response was observed in the CHF - high PCWP group, in which RV - IRT shortened significantly with increasing PEEP from 0 cm H₂O to 10 and 15 cm H₂O (from 92 ± 16 to 73 ± 6.0 to 68 ± 4.8 ms). * = $P < 0.05$ vs PEEP at 0 cm H₂O. ** = $P < 0.01$ vs PEEP at 0 cm H₂O.

cases, which can be explained by the fact that the physicians who conducted the tests were well trained in this area, and that all patients had been admitted to ICUs where sufficient sedation by medication was possible. Those with AMI suffered from anteroseptal infarction. The reason for this prerequisite was that those with infarctions of the inferior or posterior wall may also develop a RV infarct, which in turn may cause RV failure and eventually a RV diastolic dysfunction. The subject selection criterion is considered to be important in this type of study. We showed that RV diastolic dysfunction develops as the result of a decrease in TV - E/A, a shortening in TV - DcT and a prolongation in RV - IRT in CHF patients,

in comparison with the control group. These results further showed that TPR correlated significantly with TV - E/A, TV - DcT and RV - IRT. In a previous study, similar results were obtained by Yu et al.⁸⁾, who reported that RV diastolic function was impaired in patients with pulmonary hypertension, whatever the cause. Therefore, we concluded that RV dysfunction in patients with CHF was influenced by RV afterload. PaO₂ in the AMI group in this study was lower than that in the control group under FiO₂ of 1.0. Consequently, the causes of CHF in this study are possibly complicated by RV dysfunction and hypoxemia. The treatment by PEEP can be considered suitable for CHF in these cases.

In the present investigation of hemodynamic effects of graded increments of PEEP on RV diastolic function, almost identical changes in the assessed variables were noted in the control and the CHF -low PCWP group. In other words, as shown in Table 3 and 4, mPAP, RAP and RV afterload parameters increased. Furthermore, TV -E/A was decreased, TV -DcT was shortened, RV -IRT was prolonged, and CO was reduced. Our findings on the hemodynamic effects of PEEP on the intact heart and mild CHF with a left atrial pressure of below 18 mmHg are in agreement with those reported by Grace and Greenbaum⁵⁾ or those on continuous positive airway pressure (CPAP) by Hoyos and colleagues¹⁰⁾. Namely, it is presumed that PEEP acts to increase RV afterload and reduce RV diastolic function and consequently decreased CO in the intact heart and mild CHF. Similarly, Rankin et al. observed that an increase in pulmonary vascular resistance by a PEEP -associated lung volume increase acted as an RV afterload and a decrease in LV -end diastolic volume, leading to a decrease in CO⁶⁾. In our investigation, although measurements of lung volume were not performed, the mechanisms by which mPAP and TPR were increased by PEEP are considered to involve an increase in lung volume. Furthermore, RV diastolic functional parameters TV -E/A, TV -DcT and RV -IRT, as shown in Table 2, are affected by RV afterload in the pre - PEEP setting and deteriorations in these parameters by PEEP in both the groups are deemed to be due to the marked effect of a PEEP -induced RV afterload rise. On the other hand, in the CHF -high PCWP group, as shown in Table 5, although RAP rose with increasing PEEP, mPAP, TPR and SVR were decreased, whereas CO was increased. With regard to RV diastolic function, as shown in Fig 2, TV -E/A was decreased, TV -DcT was shortened, and RV -IRT was prolonged. In other words, RV diastolic function exhibited improvement with increasing PEEP. This improvement in RV diastolic function, as shown in Table 5, is presumed to be associated with a decline in RV afterload. As for the mechanisms by which positive pressure respiration offers benefits for those with impaired LV function, factors currently being explored include improvement of hypoxemia, attenuation of sympathetic nerve hyperactivity, reduction of peripheral resistance, reduction of RV preload and LV afterload by increasing intrathoracic pressure and diastolic restriction of LV by lung distention^{11~13)}. On the mechanism by which posi-

itive pressure respiration may improve the left ventricular function in patients with severe cardiac failure. Fessler et al.¹⁴⁾ concluded that systolic positive pressure reduced the afterload by increasing the systolic extracardiac pressure and diastolic positive pleural pressure reduces the afterload by decreasing the systolic intracardiac pressure through a reduction in thoracic aortic blood volume. The right and left ventricles are connected in series through the pulmonary circulation, but the two ventricles share common fiber bundles and a common septum coexisting within the same pericardial space. These features lead to the presence of parallel interactions between the ventricles whereby the function of one ventricle influences the function of the other. If the diastolic volume of one ventricle increases, then the diastolic compliance of the other decreases¹⁵⁾. Diastolic ventricular interdependence was not examined in this study, but it is suggested that this mechanism influenced the results. Genovese et al.¹⁶⁾ demonstrated that PEEP increased CO with hypervolemia in CHF. They explained that by decreasing RV preload which increased intrathoracic pressure that acted to decrease venous return. One could thus expect these mechanisms to participate in the increase in CO caused by PEEP in cases of severe heart failure. Beyar et al.¹⁷⁾ studied the hemodynamic effects of phasic variations in intrathoracic pressure timed to the cardiac cycles in a mathematical model and in experiments on dogs. They reported that both the model and the experiments on dogs showed that relatively low -amplitude intrathoracic pressure variations (< 30 -40 mmHg), rising synchronously with the onset of the cardiac systole and having an optimal duration, assist a failing heart by augmenting the aortic flow. In the present study, PEEP was conducted continuously, but the relationship between the effect of positive pressure respiration on the increase in the CO level and cardiac cycle could not be ascertained. The intrathoracic pressure was not measured but PEEP was 15 cm H₂O at its maximum and it is presumed that the increase in intrathoracic pressure was within the optimal range. Beyar et al.¹⁷⁾ reported that the magnitude of flow augmentation is inversely proportional to the peak left ventricular elastance. Cardiac contractility was not examined in severe heart failure in this report, but the increase in the CO level caused by the incremental augmentation of the pressure in PEEP suggests that an increase in cardiac contractility was involved. According to

Hassapoyannes et al.¹⁸⁾, as systolic - specific pericardial pressure increases to a magnitude of 15 and 30 mmHg, the left atrial transmural pressure decreases and CO increases, whereas decreases in left ventricular end - systolic transmural pressure and myocardial O₂ consumption are directly related. They emphasized the significance of reductions in myocardial O₂ consumption. These points are worthy of consideration for future studies. In the present investigation, these mechanisms are thought to have been implicated in the increase in CO observed in the CHF - high PCWP group.

In summary, while the application of PEEP to CHF subjects induces a rise in PaCO₂, in mild CHF subjects it produces adverse hemodynamic effects and, in parallel with this, a decline in RV diastolic function. On the other hand, in severe CHF subjects it brings about hemodynamic ameliorations as well as a rise in CO and RV diastolic functional improvement. In this patients population, PEEP is a highly relevant tool for management of CHF. This is one of the few reports in which changes in RV diastolic function caused by the application of PEEP are described. In ongoing studies, response to PEEP appears to be predictable by determining the RV diastolic function. Thus, a non - invasive assessment of the RV diastolic function by pulse - wave Doppler echocardiography during the application of PEEP is deemed highly important for an understanding of the effectiveness of PEEP therapy.

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Abbreviations :

AMI = acute myocardial infarction

DcT = deceleration time of the tricuspid or mitral E

wave

IVRT = isovolumic relaxation time

PCWP = pulmonary capillary wedge pressure

LV = left ventricle or left ventricular

RV = right ventricle or right ventricular

PEEP = positive end - expiratory pressure