Measurement of End-tidal Carbon Dioxide in Patients with Cardiogenic Shock Treated Using a Percutaneous Cardiopulmonary Assist System

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Abstract

We have reported that percutaneous cardiopulmonary assist systems (PCPS) are effective in treating life-threatening cardiogenic shock that is intractable to treatment with intraaortic balloon pumping (IABP). However, there are few clinical indices that can be used to evaluate the effectiveness of PCPS. End-tidal carbon dioxide (ET-CO₂) content reflects pulmonary blood flow. We monitored ET-CO₂ continuously and determined whether we could use it as a new index to evaluate the effectiveness of PCPS. Seventeen patients with cardiogenic shock were intubated and evaluated by ET-CO₂ monitoring during PCPS. The etiology of shock included acute myocardial infarction (n = 10), acute myocarditis (n = 2), recent coronary artery bypass graft (n = 1), cardiac rupture (n = 1), hypertrophic obstructive cardiomyopathy complicated by ventricular fibrillation (n = 1), left atrial myxoma (n = 1) and artificial valve malfunction (n = 1). PCPS was extremely effective in 10 of 17 patients (58.8%), and they recovered from the cardiogenic shock. The remaining 7 patients did not recover from shock, and died during PCPS. Six of ten patients who recovered from shock were successfully weaned from PCPS and 4 patients had good long-term survival. In the cases where PCPS was effective, the ET-CO₂ measured soon after the beginning of PCPS was significantly higher than in the cases in which PCPS was ineffective. Furthermore, the ET-CO₂ content increased gradually with the improvement in hemodynamics. In contrast, ET-CO₂ content remained low if PCPS was not effective. The ET-CO₂ represents a useful predictor of survival or death and is also a good index for weaning in patients treated with PCPS.

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Key words: end-tidal carbon dioxide (ET-CO₂), percutaneous cardiopulmonary assist system (PCPS), cardiogenic shock

Introduction

We have previously reported that the percutaneous cardiopulmonary assist system (PCPS) is effective for treating extremely serious cardiogenic shock that is refractory to intraaortic balloon pumping (IABP)¹. However, there are few...
clinical indices that can be used to evaluate the effectiveness of PCPS. Hemodynamic measurements using a Swan-Ganz catheter or echocardiography do not reflect actual pulmonary blood flow or cardiac output in patients treated by PCPS because of venous drainage from the right atrium.

The end-tidal carbon dioxide (ET-CO₂) content reflects pulmonary blood flow. The ET-CO₂ has been shown to correlate with cardiac output during and after cardiopulmonary resuscitation (CPR). Active compression-decompression cardiopulmonary resuscitation increases ET-CO₂. ET-CO₂ is also an accurate predictor of coronary perfusion pressure. However, in patients who survive resuscitation, the ET-CO₂ content is not affected by either technique. Levine et al. reported that the ET-CO₂ content measured during resuscitative efforts is a predictor of death from cardiac arrest in patients with electrical activity but no pulse.

In this study, we monitored ET-CO₂ continuously and determined whether we could use it to evaluate the effectiveness of PCPS in the setting of severe cardiogenic shock.

**Materials and Methods**

**Study Design**

This study is a retrospective study in which we always paid attention to ethical considerations regarding all patients.

**Patients**

From March 1996 to December 2002, 17 patients with profound cardiogenic shock underwent PCPS. The age of the patients ranged from 12 to 81 years. Among these cases, 11 were men and 6 were women. Eleven had acute myocardial infarction (1 resulting in cardiac rupture), 2 had fulminant myocarditis and 1 had hypertrophic obstructive cardiomyopathy (HOCM) complicated by ventricular fibrillation (Table 1).

All patients had cardiogenic shock and were...
treated with dopamine and dobutamine at doses exceeding 10 \( \mu \text{g/kg/min} \). IABP therapy was instituted in 15 of the patients. Four patients with acute myocardial infarction underwent percutaneous transluminal coronary angioplasty. Eight patients with anuria received continuous hemodialfiltration (CHDF). Two patients with advanced AV block received temporary RV pacing. Surgical procedures were performed in three patients to treat cardiac rupture, left atrial myxoma, or artificial valve malfunction, respectively.

**Definition of Cardiogenic shock**

Cardiogenic shock was confirmed by the following clinical criteria of the Myocardial Infarction Research Unit (MIRU)\(^1\): (1) A systolic arterial pressure less than 90 mmHg or 30 mmHg below the previous basal level. (2) Evidence of reduced blood flow as shown by (all should be present): (a) Urine output less than 20 ml/hour, preferably with a low sodium content. (b) Impaired mental function. (c) Peripheral vasoconstriction associated with a cold, clammy skin.

**Effect of the PCPS and Group Classification**

The PCPS system used in all cases consisted of a centrifugal pump manufactured by St. JUDE Medical (Lifefstream USA), a hollow-fiber oxygenator (Kurare Inc. Japan) and connection tubes. With use of the Seldinger technique, Teflon cannulas were inserted into the femoral artery (14 F) and vein (17 F) and the tip of the venous cannula was placed in the right atrium.

PCPS was performed as a circulatory assist procedure in 17 patients with profound cardiogenic shock. The mean blood flow (max) achieved with PCPS was 26 L/min (range: 2.0 to 4.0 L/min). Patients were maintained on PCPS for a mean duration of 57 hours 6 minutes (range 1.97 to 208.50 hours). PCPS was extremely effective in 10 (effective group; BP increased over 90 mmHg and urine output increased over 20 ml/hr during one hour) of the 17 patients (58.8%), and they recovered from the cardiogenic shock. Six (weaned group) of ten patients who recovered from shock were successfully weaned from PCPS and 4 patients (23.5%) had good long-term survival. Another 4 patients (dependent group) who recovered from the shock were not weaned from PCPS and died. The most common cause of death in the 6 who did not survive was multi-organ failure (MOF) complicated by infection. The remaining 7 patients (ineffective group) did not recover from cardiogenic shock, and died during PCPS.

**Measurement of ET-CO\(_2\)**

All patients had undergone endotracheal intubation and received mechanical assist ventilation. The endotracheal tube was connected to a combined pulse oximeter-capnograph (Cosmos 7,100, Novametrix Medical Systems USA). ET-CO\(_2\) measurements were performed by mainstream sampling with a lightweight sensor attached directly to the endotracheal tube (Fig. 1) under mechanical assist ventilation.

The initial measurement of ET-CO\(_2\) was made soon after the start of PCPS and the highest value during one minute was adopted. It was performed repeatedly until PCPS was discontinued. Measurements of hemodynamic parameters (arterial blood pressure, heart rate, urine production) were performed simultaneously. Because of the unstable condition of the patients, these data could not be recorded before starting PCPS.
**Statistical Analysis**

The initial measurement values and the last measurement values recorded just before the discontinuation of PCPS are presented as the mean ± standard deviation. Differences between the two measurements were assessed by paired Student’s t test. To assess the difference of ET-CO₂ and hemodynamic parameters in the three groups above mentioned (effective group, weaned group, ineffective and dependent group), Student’s t test and Fisher’s exact test were used. A p value of <0.05 was considered significant.

**Results**

In all patients, the ET-CO₂ measured soon after the initiation of PCPS was 14.7 ± 8.1 mmHg and increased to 24.4 ± 9.1 mmHg at the final measurements (p = 0.00009: Fig. 2). The initial ET-CO₂ clearly discriminated between the group that responded to PCPS and the group in which PCPS was ineffective, averaging 19.5 ± 7.0 mmHg (range: 8 to 31 mmHg) in the effective group and 7.9 ± 2.7 mmHg (range: 4 to 11 mmHg) in the ineffective group (p = 0.0064). The final ET-CO₂ also discriminated between the effective group and the ineffective group (p = 0.0405), averaging 26.8 ± 7.3 mmHg (range: 18 to 36 mmHg) in the effective group and 13.7 ± 4.7 mmHg (range: 6 to 20 mmHg) in the ineffective group. The result of Fisher’s exact test with the initial ET-CO₂ dichotomized at a value of 10 mmHg was significant (p = 0.0278). The result of the same test with the final ET-CO₂ dichotomized at a value of 18 mmHg was also significant (p = 0.0333).

The initial ET-CO₂ in the PCPS dependent group (14.5 ± 4.7 mmHg) was lower than the content in the weaned group (22.8 ± 6.5 mmHg: p = 0.0028). The final ET-CO₂ was 22.3 ± 4.9 mmHg in the dependent group and 29.8 ± 7.4 mmHg in the weaned group, but the difference between the two groups was not significant (p = 0.1184). All patients in the weaned group had an initial ET-CO₂ > 18 mmHg and all patients in the dependent group had a final ET-CO₂ < 28 mmHg.

The ET-CO₂ of a representative patient (Case 7) in the dependent group illustrates changes that are dependent on pump flow (Fig. 3: left). In contrast, a high ET-CO₂ observed in one patient in the weaned group was hardly influenced by changes in pump flow (Fig. 3: right).

The hemodynamic parameters are summarized in Table 2. The maximum blood pressure (max BP) was extremely low before PCPS and increased significantly (p = 0.0001) from 46.8 ± 20.1 mmHg to 91.8 ± 25.3 mmHg during PCPS. The minimum blood pressure (min BP) also increased to 50.6 ± 20.6 mmHg...
Fig. 3 Relationship between PCPS pump flow and ET-CO₂.
The ET-CO₂ of a patient (Case 7) in the dependent group revealed changes dependent on pump flow (left). In contrast, high ET-CO₂ were observed in one patient in the weaned group (Case 4); the ET-CO₂ was hardly influenced by changes in pump flow (right).

<table>
<thead>
<tr>
<th></th>
<th>pre PCPS</th>
<th>during PCPS</th>
<th>p value</th>
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<tr>
<td><strong>Hemodynamic parameters</strong></td>
<td></td>
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<tr>
<td>HR (/min)</td>
<td>98.3 ± 26.6</td>
<td>101.2 ± 28.6</td>
<td>0.5621</td>
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<tr>
<td>BPs (mmHg)</td>
<td>46.8 ± 20.1</td>
<td>91.8 ± 25.3</td>
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</tr>
<tr>
<td>BPD (mmHg)</td>
<td>25.0 ± 12.8</td>
<td>50.6 ± 20.6</td>
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<td>CVP (mmHg)</td>
<td>11.9 ± 4.8</td>
<td>10.4 ± 4.9</td>
<td>0.6842</td>
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<tr>
<td>UV (ml/hr)</td>
<td>3.0 ± 6.5</td>
<td>129.2 ± 157.8</td>
<td>0.0338</td>
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<tr>
<td><strong>Blood gas analysis</strong></td>
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<tr>
<td>pH</td>
<td>7.27 ± 0.15</td>
<td>7.42 ± 0.16</td>
<td>0.0416</td>
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<tr>
<td>PO₂ (mmHg)</td>
<td>198 ± 104</td>
<td>209 ± 73</td>
<td>0.9172</td>
</tr>
<tr>
<td>PCO₂ (mmHg)</td>
<td>36.0 ± 18.7</td>
<td>40.0 ± 23.5</td>
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<tr>
<td>BE</td>
<td>−12.0 ± 7.5</td>
<td>−21.1 ± 11.4</td>
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<td>SaO₂ (%)</td>
<td>90.7 ± 26.0</td>
<td>99.5 ± 0.3</td>
<td>0.3139</td>
</tr>
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from 25.0 ± 12.8 mmHg (p = 0.0008). There were no changes in heart rate (HR) or central venous pressure (CVP) during PCPS. The urine volume (UV) after PCPS was significantly greater than that before PCPS (p = 0.0338).

**Fig. 4** shows changes of max BP and UV. Max BP was more highly increased in the two effective groups (weaned group and dependent group) than in the ineffective group but the difference between the weaned and dependent groups was not significant (left side). The UV was also significantly greater in the two effective groups than in the ineffective group during PCPS. After 6 hours of PCPS, the UV in the weaned group was greater than in the dependent group (right side) and the UV measured before the termination of PCPS in the weaned group was no different from that in the dependent group.

PCPS improved metabolic acidosis remarkably, but did not differ within the three groups.
Discussions

The ET-CO$_2$ content is determined by carbon dioxide production, alveolar ventilation, and pulmonary blood flow. The ET-CO$_2$ has been shown to correlate with cardiac output during and after cardiopulmonary resuscitation (CPR). Therefore, ET-CO$_2$ represents a useful predictor of survival after cardiac arrest. Callaham et al. found that the initial ET-CO$_2$ content determined after prolonged cardiac arrest and cardiopulmonary resuscitation predicts survival, with values averaging 19 mmHg in survivors and 5 mmHg in nonsurvivors. A threshold ET-CO$_2$ content of 15 mmHg in that study had the best sensitivity and specificity for identifying survivors with positive and negative predictive values of 91%. Levine et al. reported a threshold effect between 10 and 18 mmHg. Specifically, no patient who had an ET-CO$_2$ content <10 mmHg survived. Conversely, in all patients in whom spontaneous circulation was restored, the ET-CO$_2$ increased to at least 18 mmHg before detectable changes in the vital signs.

Reichman et al. used PCPS in patients in whom standard cardiopulmonary resuscitation was ineffective or who had a fatal arrhythmia. In such patients, PCPS supported cardiopulmonary function and allowed diagnostic and therapeutic interventions to be used. We also reported previously that PCPS is effective for the treatment of extremely serious cardiogenic shock when IABP is not effective. However, there are few clinical indices that can be used to measure the effectiveness of PCPS. Hemodynamic measurements using a Swan-Ganz catheter or echocardiography do not reflect true pulmonary blood flow or native cardiac output in patients receiving PCPS because of blood drainage from the right atrium to the femoral artery.

Even in the setting of shock, if minute ventilation is held constant, changes in the ET-CO$_2$ concentration will predominantly reflect pulmonary blood flow and indirectly, cardiac output. Therefore, we hypothesized that the effectiveness of PCPS can be evaluated by measuring the ET-CO$_2$.

In our study, no patient who had an initial ET-CO$_2$ content <10 mmHg survived, in keeping with the findings of Levine et al. The initial ET-CO$_2$ content in the PCPS dependent group was also lower than the content in the weaned group. The final ET-CO$_2$ content was $22.3 \pm 4.9$ mmHg in the dependent group and $29.8 \pm 7.4$ mmHg in the weaned group, but the difference between the two groups was not significant. All patients in the weaned group had an initial ET-CO$_2$ >18 mmHg and all of the patients who could not be weaned from PCPS had a final ET-CO$_2$.
<28 mmHg.

Based on these findings, PCPS is ineffective in treating patients if the initial ET-CO₂ is less than 10 mmHg. If the initial ET-CO₂ is less than 18 mmHg or the late ET-CO₂ does not exceed 28 mmHg, it can be predicted that the patient will not be weaned from PCPS. Therefore, ET-CO₂ represents a useful predictor of survival and also a good index for weaning in patients treated with PCPS. Based on our results, various strategies for treating severe pump failure can be evaluated. In patients with extremely serious cardiogenic shock in which IABP therapy is not effective, PCPS should be attempted for several days. If PCPS is ineffective, then a ventricular assist device (VAD) should be used immediately. If native cardiac function does not recover and PCPS cannot be weaned, indication of a VAD implantation should be considered.

References


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