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End-Tidal CO_2 for Prediction of Cardiac Output Following Weaning from Cardiopulmonary Bypass

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Abstract: This prospective study included 32 patients undergoing cardiopulmonary bypass (CPB) for elective coronary artery bypass grafting correlates the respiratory end-tidal CO_2 ($ETCO_2$) during partial separation from CPB with cardiac output (CO) following weaning from CPB. After induction of general anesthesia, a pulmonary artery catheter was inserted for measurement of cardiac output by thermodilution. Patients were monitored using a 5-lead ECG, pulse oximeter, invasive blood pressure monitoring, rectal temperature probe, and end-tidal capnography. At the end of surgery, patients were weaned from CPB in a stepwise fashion. Respiratory $ETCO_2$ and in-line venous oximetry were continuously monitored during weaning. The $ETCO_2$ was recorded at quarter pump flow and after complete weaning from CPB. Following weaning from CPB, CO was measured by thermodilution. The CO values were correlated with the $ETCO_2$ during partial bypass and following weaning from bypass. Regression analysis of $ETCO_2$ at quarter-flow and post-bypass CO showed significant correlation ($r = 0.57$, $p < .001$). Also, regression analysis of $ETCO_2$ after complete weaning from bypass and post-bypass CO showed significant correlation ($r = 0.6$, $p = .002$). The correlation between $ETCO_2$ and CO showed that an $ETCO_2$ >30 mm Hg during partial CPB will always predict an adequate CO following weaning from CPB. An $ETCO_2$ <30 mm Hg may denote either a low or a normal cardiac output and hence other predictive parameters such as SvO_2 must be added. **Keywords:** end-tidal CO_2, cardiac output, cardiopulmonary bypass, weaning. *JECT. 2004;36:255–257*

Baraka et al. have recommended the use of mixed venous oxygen saturation (SvO_2) immediately before weaning from cardiopulmonary bypass (CPB) as a simple technique for predicting post-bypass cardiac output (CO) (1). Also, Maslow et al. have recently shown that there is a close correlation between end-tidal CO_2 ($ETCO_2$) and pulmonary artery blood flow, suggesting that the $ETCO_2$ can be used to assess the post-weaning cardiac output (2).

The present report is a prospective study in patients undergoing elective coronary artery bypass grafting (CABG) during CPB. The report correlates the $ETCO_2$ during partial separation from CPB and after complete weaning with the post-bypass CO, as monitored by the thermodilution technique.

MATERIALS AND METHODS

Thirty-two adult patients (ASA III-IV) scheduled for elective CABG with the use of CPB gave informed consent and were included in the study. All patients with pre-existing pulmonary disease were excluded. General anesthesia was induced using sufentanil 1 $\mu g/kg^{-1}$, midazolam 0.05 mg/kg^{-1} followed by rocuronium 0.9 $mg.kg^{-1}$. Anesthesia was then maintained by isoflurane 1–3% in 100% O_2, muscle relaxants and opioids as needed. After induction, a pulmonary artery catheter was inserted for measurement of cardiac output by thermodilution (Arrow international, Inc. PA). All patients were monitored using a 5-lead ECG, pulse oximeter, invasive blood pressure monitoring using the radial artery, rectal temperature probe, and end-tidal capnography (Novametrix Medical Systems, model 1265, CT). A heart–lung machine was used (Sarns, model 8000, Ann Arbor, MI), with an oxygen–air blender (Sechrist Inc., Anaheim, CA), an in-line oxygen monitor (Ohmeda, Louisville, CO), and an oxy-sat meter for the measurement of SvO_2 on the venous line (Baxter Health Care Corp., Irvine, CA). The system used was a Baxter–Bentley open membrane system, utilizing a Univox oxygenator and a Bentley open cardiotomy venous reservoir. The Bypass circuits included a Baxter arterial filter. After priming the pump with crystalloid solution, CPB proceeded according to the institution's routine

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using a continuous flow, set at 2.4 L/min^{-1}/m^2 with moderate hypothermia (30–33°C), using intermittent cold cardioplegia.

When the patients were normothermic (36.3–37.2°C), having a hematocrit above 25%, and immediately before weaning from bypass, arterial blood gases were analyzed, SvO_2 was recorded, and ventilation was resumed with a tidal volume of 7 mL/kg^{-1} and a respiratory rate of 12.min^{-1}. The patients were then weaned from CPB in a stepwise fashion. $ETCO_2$ was continuously monitored during weaning from CPB as well as the SvO_2. The $ETCO_2$ values were recorded when the pump flow was decreased down to its quarter volume and after complete weaning from CPB. Following weaning from CPB, CO was measured in triplicate by thermodilution using 10 mL of room temperature saline, the mean value being used for calculation. The mean CO values were correlated with the $ETCO_2$ during partial bypass and following weaning from bypass.

Statistics

Standard techniques of linear regression and correlation by the least-squares method were used to assess the degree of correlation between the post-bypass cardiac output and the $ETCO_2$ values at quarter pump flow as well as after weaning from bypass. Student's *t*-test was used for statistical analysis of the correlation coefficients. Statistical significance was considered at the 5% level (i.e., $p < .05$).

RESULTS

Patients' characteristics are shown in Table 1. The mean arterial PCO_2 immediately before weaning from bypass was 38 ± 4 mmHg. Regression analysis of $ETCO_2$ at quarter flow and post-bypass CO showed significant correlation $r = 0.57$, $p < .001$ (Figure 1). Also, regression analysis of $ETCO_2$ after complete weaning from bypass and post-bypass CO showed significant correlation, $r = 0.6$, $p = .002$ (Figure 2).

As shown in Figures 1 and 2, whenever the $ETCO_2$ is >30 mmHg, the CO following bypass is always > 4.5 L/min. However, an end-tidal CO_2 < 30 mmHg is associated with either low or normal CO. In all patients with a cardiac output > 4.5 L/min^{-1}, the SvO_2 at quarter pump flow ranged between 70–85%. In the patient with the cardiac output of 3.4 L/min^{-1}, the SvO_2 was 67%.

Table 1. Patients' characteristics.

	$n = 32$
Age (year)	65.2 ± 9
Height (cm)	166.5 ± 8.6
Weight (kg)	79 ± 12
Ejection Fraction (%)	50 ± 5
Pre bypass cardiac output (L/min^{-1})	4.6 ± 0.9
Duration of bypass (min)	75.2 ± 9.1
Mixed venous O_2 saturation at full pump flow (%)	79.2 ± 7.3
Mixed venous O_2 saturation at quarter pump flow (%)	81 ± 6.5

All values are expressed as mean ± SD.

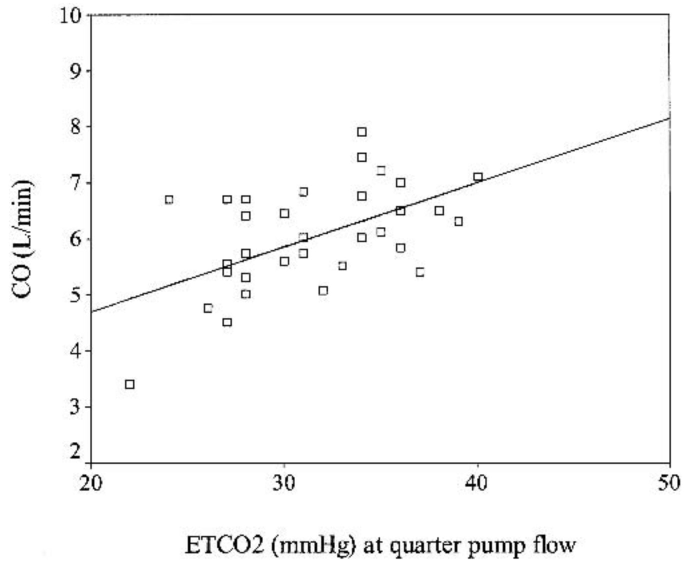

Figure 1. Correlation between the post-bypass cardiac output (CO) expressed in L/min^{-1} and the end-tidal CO_2 ($ETCO_2$) expressed in mmHg at quarter cardiopulmonary pump flow (r = 0.57).

DISCUSSION

Weaning from CPB requires continuous assessment of myocardial function and blood flow because patients are at risk of circulatory failure after CPB. Thermodilution technique is considered the gold standard for CO mea-

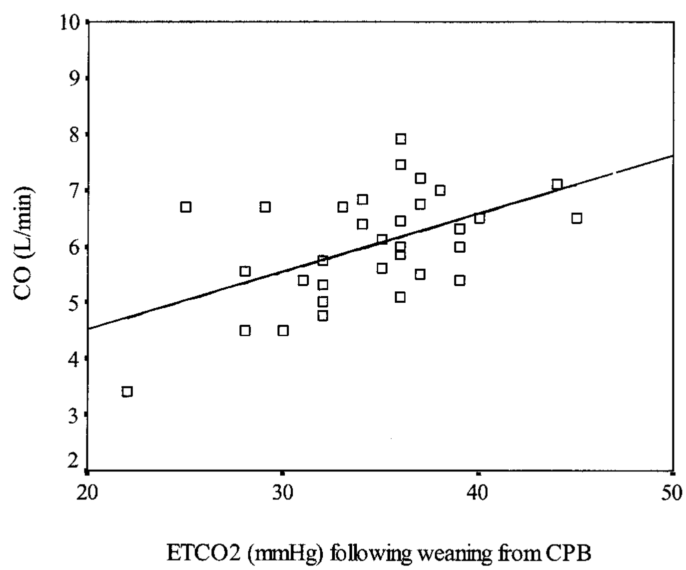

Figure 2. Correlation between the post-bypass cardiac output (CO) expressed in l.min^{-1}and the end-tidal CO_2 ($ETCO_2$) expressed in mmHg following weaning from cardiopulmonary bypass (r = 0.6).

surement. However, this technique is not accurate during bypass because variable quantities of injectate are removed by the venous return cannula of the CPB circuit (2). Previous studies have shown a direct relationship between changes in $ETCO_2$ and CO and have demonstrated the usefulness of $ETCO_2$ in assessing pulmonary blood flow and cardiac output in a variety of clinical scenarios, such as cardiac arrest, circulatory shock, and during major abdominal surgeries (3–7). Studies in animals demonstrate an excellent correlation between CO and $ETCO_2$ levels in states of low and very low CO (6). Isserles et al. have shown that, during constant minute ventilation and tissue CO_2 production, an abrupt reduction in blood flow reduces $ETCO_2$ via two mechanisms. First, a reduction in venous return causes a decrease in delivered CO_2 to the alveoli, resulting in a decrease in alveolar $PaCO_2$ and, consequently, $ETCO_2$. Second, reduced pulmonary vascular flow will result in an increase in alveolar dead space, which will dilute the CO_2 from normally perfused alveolar spaces, thus decreasing $ETCO_2$ below $PaCO_2$ (5).

$ETCO_2$ is slightly lower than the partial pressure of arterial CO_2 (P_ACO_2) (3). $ETCO_2$ is determined by the venous partial pressure of CO_2 (P_VCO_2), the degree of ventilation–perfusion mismatch and the pulmonary blood flow reflecting the cardiac output (3). P_VCO_2 depends on tissue CO_2 production, metabolism, and CO_2 solubility in blood as determined by patient's temperature (2). $ETCO_2$ may not accurately reflect CO in chronic low-flow status when the $ETCO_2$ gradually increases toward baseline, despite reduction in pulmonary blood flow (5). Also, using $ETCO_2$ for hemodynamic assessment may be limited in patients with significant pulmonary disease because of a possible increase of the arterial–alveolar carbon dioxide gradient (2). In addition, at normal CO values, $ETCO_2$ reflects primarily ventilation rather than pulmonary blood flow (4). However, during low-flow states, and in patients without significant pulmonary lung disease and at constant minute volume, metabolic rate and temperature, $ETCO_2$ levels reflect predominantly pulmonary blood flow (6).

In the present report, we demonstrated a significant correlation between the $ETCO_2$ immediately after weaning from CPB and the post-bypass CO. Also, there was a significant correlation between the $ETCO_2$ at quarter flow and the post-bypass CO. Correlation between the $ETCO_2$ during partial bypass as well as following weaning from bypass with the post-bypass CO shows that an $ETCO_2$ >30 mmHg is always associated with CO > 4.5 L/min^{-1}. However, an $ETCO_2$ < 30 mmHg may be associated with either a low or a normal cardiac output. More cases with low cardiac output may be needed to confirm the correlation between low $ETCO_2$ and CO at low cardiac output values. The association of normal CO with low $ETCO_2$ in some of our patients may be attributed to an increased physiologic dead space and/or to a relative hyperventilation during or following CPB. Thus, additional predictive parameters such as SvO_2 must be added. Baraka et al. had previously used the SvO_2 as a simple and reliable method of prediction of post-CPB cardiac output (1). Hence, a low $ETCO_2$ associated with a high SvO_2 can denote a normal CO, while the association of a low $ETCO_2$ and a low SvO_2 will predict a low CO. The combination of a high $ETCO_2$ and a high SvO_2 at quarter pump flow will optimize the criteria predicting a normal CO following weaning from CPB. The early prediction of the CO before complete weaning from CPB is clinically advantageous because it allows the anesthesiologist to optimize the hemodynamics by preload augmentation and/or inotropes while supporting the heart by partial bypass.

In conclusion, the present report shows in patients undergoing CABG a significant correlation between $ETCO_2$ during partial separation from cardiopulmonary bypass and cardiac output following weaning from CPB; an $ETCO_2$ > 30 mmHg during partial CPB will always predict an adequate CO following weaning from CPB. However, an $ETCO_2$ < 30 mmHg may denote either a low or a normal cardiac output and, hence, other predictive parameters such as SvO_2 must be added. The combination of $ETCO_2$ and SvO_2 will optimize the criteria predicting post-bypass CO.

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