Original Article

Prediction of Post-Cardiopulmonary Bypass Cardiac Output by Venous Oximetry

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Abstract

The present study evaluates two equations for predicting the post-cardiopulmonary bypass cardiac output (CO) in 10 patients undergoing coronary artery bypass grafting. One equation is based on the relationship of CO with mixed venous oxygen saturation (SVO₂), while the second equation is based on the relationship with oxygen extraction (1 - SVO₂). Each patient served as his own control. During bypass, when the patients were normothermic and perfused with a pump flow of 2.4 L/min/m², the SVO₂ was monitored by an in-line Bentley oxystat Meter. Just before termination of bypass, the pump flow was decreased to 0.4 L/min/m² and the left atrial pressure was increased to 10-15 mmHg; the resulting SVO₂ was recorded. The post-bypass CO was predicted in every patient by the two equations. Immediately after weaning from bypass, the cardiac output was measured by thermodilution. The thermodilutional CO measurement was correlated with the CO predicted by the two equations. Correlation analysis suggests that CO prediction is more accurate and approaches the 1:1 ratio when the calculation of predicted CO is based on the relationship between cardiac output and oxygen extraction.

VO₂ = Whole-body oxygen consumption (mL/min)
CO = Cardiac output (L/min)

Hemoglobin conc = Hemoglobin concentration (g/dL)

1.38 = mL oxygen bound to 1 gm of hemoglobin when fully saturated

SaO₂ = Arterial oxyhemoglobin saturation
SVO₂ = Mixed venous oxyhemoglobin saturation

Weaning from CPB is of such short duration that oxygen consumption, hemoglobin concentration and arterial oxygen saturation can be assumed unchanged (2,3). Thus, CO will be inversely related to 1 - SVO₂, assuming that arterial hemoglobin remains fully saturated. The post-bypass CO can be

Introduction

Cardiac output (CO) after cardiopulmonary bypass (CPB) is one of the most reliable measurements of cardiac function (1). The CO early after CPB can be predicted by a simplified calculation based on the oxygen consumption equation (2):

\[ VO₂ = CO \times [\text{Hemoglobin conc} \times 1.38 (SaO₂ - SVO₂)] \]

\[ CO = \frac{VO₂}{[\text{Hemoglobin conc} \times 1.38 (SaO₂ - SVO₂)]} \]
predicted by the following formula:

**Equation 1:**

\[ Q_{(2)} = Q_{(1)} \times \frac{1 - SVO_2 (1)}{1 - SVO_2 (2)} \]

1. **Q(1) = perfusion flow (2.4 L/min/m²) during CPB**
2. **Q(2) = predicted CO (L/min/m²)**
3. **SVO₂ (1) = central venous oxygen saturation during the full perfusion flow**
4. **SVO₂ (2) = central venous oxygen saturation at the low perfusion flow (0.4 L/min/m²)**

Chung and his colleagues (2), simplified the equation by assuming a proportional and a 1:1 ratio between SVO₂ and Q:

**Equation 2:**

\[ Q_{(2)} = Q_{(1)} \times \frac{SVO_2 (2)}{SVO_2 (1)} \]

The present report compared the two equations for prediction of post-CPB cardiac output. Each patient served as his own control.

**Materials and Methods**

Investigations were carried out on 10 adult patients undergoing coronary artery bypass grafting utilizing CPB. Their mean age was 56.0 ± 9.0 years, weight 78.0 ± 12.0 kg and surface area 1.88 ± 0.23 m². The investigation was approved by the Institution Research Committee, and an informed consent was obtained from all patients.

A Swan-Ganz thermodilution catheter was inserted in all patients for CO measurement using the Edwards cardiac output computer. Anesthesia was induced with midazolam 0.15 mg/kg and fentanyl 50 µg/kg while neuromuscular blockade was achieved by a mixture of vecuronium 0.1 mg/kg and pancuronium 0.1 mg/kg. CPB was instituted using a pump flow of 2.4 L/min/m², and the oxygenator was ventilated with an equal flow of 100% oxygen. The patients were rapidly cooled to a central venous temperature of 27°C to 30°C. The aorta was cross-clamped proximal to the arch vessels, and cardioplegia was achieved by cold crystalloid solution containing 20 meq/L K⁺. The left ventricle was vented by a sump placed through the right superior pulmonary vein. Throughout CPB, SVO₂ was continuously monitored using the Bentley Oxystat Meter incorporated in the venous line of the extracorporeal circuit (4).

Rewarming of the patient started soon before the release of the aortic cross-clamp. When the central venous blood temperature stabilized at 37°C, the SVO₂ at the perfusion flow of 2.4 L/min/m² was recorded. Weaning from CPB was carried out in a stepwise manner. The venous line to the oxygenator was progressively clamped, while the pump flow was decreased to 0.4 L/min/m², and the left atrial pressure was increased to 10-15 mmHg. The resulting SVO₂ was recorded.

The CO early after CPB was then predicted in every patient by the two equations:

**Equation 1:**

\[ Q_{(2)} = Q_{(1)} \times \frac{1 - SVO_2 (1)}{1 - SVO_2 (2)} \]

**Equation 2:**

\[ Q_{(2)} = Q_{(1)} \times \frac{SVO_2 (2)}{SVO_2 (1)} \]

Following weaning from CPB, the CO was immediately measured by thermodilution. The measurement was done by an anesthesiologist who was not informed about the CO prediction. The CO was determined by the average of three serial CO values.

Correlation analysis was used to compare the values obtained by the two equations of CO prediction with the post-bypass thermodilution CO values. The correlation coefficient r, the slope B, and the A intercept were calculated.

**Results**

Data analysis was performed through two stages. First, scatter diagrams were drawn to depict trends of cardiac output values (L/min) measured by thermodilution as compared to values of cardiac output (L/min) predicted by Equation 1 and Equation 2 on the other. Figures 1 and 2 show individual values of cardiac output measured by thermodilution plotted against corresponding values of cardiac output predicted by either Equation 1 or Equation 2.

Second, Least Squares Regression Lines were constructed to show the linear relationship between these variables. Table 1 gives the summary results of our calculations.
Discussion

SVO₂ has been suggested for prediction of post-bypass CO according to the following equation:

\[ Q_{(2)} = \frac{Q_{(1)} \times SVO₂}{SVO₂ (1)} \]

The formula assumes a proportional and a 1:1 ratio between SVO₂ and Q(2).

In the present report, using the SVO₂ formula for prediction of post-bypass CO shows a correlation coefficient of 0.83 which is significant. However, the slope B is 0.40 and the A intercept is 2.49.

When the equation:

\[ Q_{(2)} = \frac{Q_{(1)} \times 1 - SVO₂}{1 - SVO₂ (2)} \]

was used for CO prediction, the correlation coefficient increased to 0.97. Also, the slope B became 0.92 and the A intercept 0.26, denoting almost a 1:1 ratio between the predicted and measured cardiac output.

We conclude that prediction of CO according to oxygen extraction (1 - SVO₂) is more accurate than prediction according to SVO₂. Previous reports have also shown that CO shows better correlation with oxygen utilization than with mixed venous oxygen saturation (5). The technique provides a simple and reliable method for prediction of CO immediately following CPB, and can be used to assess the need for inotropic support prior to complete weaning from bypass. The technique may be also advantageous whenever a thermodilution pulmonary artery catheter has not been inserted in a patient undergoing CPB.

References

Table 1
Summary Results of Pearson Correlation Coefficient and Least Squares Regression Line of Thermodilutional Cardiac Output (L/min) by Predicted Cardiac Output (L/min) through Equation 1 and Equation 2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Correlation Coefficient</th>
<th>Standard Error of Estimate</th>
<th>p-value</th>
<th>Intercept (std err)</th>
<th>Slope (std err)</th>
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<tr>
<td>EQ1</td>
<td>.97</td>
<td>.37</td>
<td>.0001</td>
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<tr>
<td>EQ2</td>
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<td>.42</td>
<td>&lt;.002</td>
<td>2.49</td>
<td>(.47)</td>
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</tbody>
</table>

*EQ1 = Predicted Cardiac Output based on Oxygen Extraction (1 - SV0₂).
EQ2 = Predicted Cardiac Output based on Venous Oxygen Saturation (SV0₂).