Original Article

**Alpha-Stat Capnography for the Sorin Monolyth Oxygenator**

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**ABSTRACT**

Monitoring the carbon dioxide exhaust of an oxygenator is an inexpensive method to accurately predict and control the arterial carbon dioxide tension during cardiopulmonary bypass (CPB). The partial pressure of carbon dioxide in the exhaust ventilating gas (p_{ex}CO_{2}) was continuously monitored from the capnograph port of the Sorin Monolyth oxygenator during CPB. At the time of routine arterial blood gas sampling, the arterial blood temperature (ABT) was recorded along with the p_{ex}CO_{2} from the capnograph monitor. The arterial carbon dioxide tension (paCO_{2}) from the arterial blood sample analysis was then statistically analyzed and related to the p_{ex}CO_{2} and ABT. The statistical relationship of p_{ex}CO_{2} and ABT while employing alpha stat ventilation resulted in an exponential regression with a correlation coefficient of 0.98. The exponential regression is unique to each manufacturer's oxygenator; we have titled this the "regression signature." This regression signature can be easily learned and employed by the perfusionist during CPB as an aid in controlling oxygenator ventilation.

The mean paCO_{2} value obtained during the study period was 39.0 ± 2.5 mmHg. There was no statistical difference between the paCO_{2} values when separated into four different blood temperature groups, (<28, 28-32, 32-37, and >37°C).

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INTRODUCTION

Capnography is used to monitor the mechanical ventilation circuit in most operating rooms. During cardiac surgery procedures, the capnograph monitor is not used during the period that the patient is on cardiopulmonary bypass (CPB). Several reports have produced conflicting results on the accuracy of estimating the arterial carbon dioxide tension (paCO₂) with oxygenator exhaust capnography (1-4).

We have used oxygenator exhaust capnography to monitor and direct alpha-stat blood gas management during CPB since our conversion to membrane oxygenators in 1987. The relationship of the carbon dioxide in the exhaust ventilating gas (p₂CO₂), arterial blood temperature (ABT) and the paCO₂ varies by type of membrane and manufacturer. The information from this relationship, which we have titled the “regression signature,” can be used to predict and control the paCO₂ during CPB.

The Monolyth oxygenator is the only oxygenator to date that incorporates a capnograph port within the gas scavenging connector of the oxygenator. This permits consistent placement of a sampling line to monitor the oxygenator’s expired gas.

This paper discusses the generation of the regression signature for the Monolyth oxygenator during CPB while employing alpha-stat ventilation techniques. This regression signature is specific for the Monolyth oxygenator and cannot be accurately used for any other gas exchange device.

MATERIALS AND METHODS

The capnograph port within the oxygenator was fitted with 2.1 meters of low pressure medical gas supply tubing which was connected to 3 meters of standard capnograph monitoring tubing fitted with a moisture filter for connection to the capnograph. With the capnograph sampling rate set to high, the response time of the system was eleven seconds. The response time was measured by exhaling into the sampling line and measuring the period of time until a carbon dioxide bolus was indicated on the capnograph monitor.

The perfusion circuit included a positive displacement roller pump, a 4:1 blood cardioplegia set and a custom tubing pack.

Twenty-six patients were studied using the Monolyth oxygenator to produce the regression signature. The capnograph was switched from the mechanical ventilation circuit to the oxygenator circuit at the initiation of CPB. The p₂CO₂ of the oxygenator was monitored continuously during CPB. Alpha-Stat ventilation was practiced during CPB. Arterial blood samples were taken at various periods of CPB by the perfusionists.

METHODS

Arterial Blood Temperature (ABT) and the direct alpha-stat blood gas management during CPB since exhaust capnography (1-4).

TABLE 1

<table>
<thead>
<tr>
<th>Patients</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial Blood Samples</td>
<td>62</td>
</tr>
<tr>
<td>Mean paCO₂</td>
<td>39.0 mmHg</td>
</tr>
<tr>
<td>Median</td>
<td>38.9 mmHg</td>
</tr>
<tr>
<td>Mode</td>
<td>38.9 mmHg</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>2.5 mmHg</td>
</tr>
<tr>
<td>Minimum</td>
<td>34.0 mmHg</td>
</tr>
<tr>
<td>Maximum</td>
<td>45.3 mmHg</td>
</tr>
</tbody>
</table>

paCO₂ = partial pressure of carbon dioxide in arterial blood sample in mmHg.

TABLE 2

<table>
<thead>
<tr>
<th>ABT (°C)</th>
<th>Mean paCO₂ (mmHg)</th>
<th>p value</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. &gt;37</td>
<td>38.7</td>
<td>&lt;0.001</td>
<td>22</td>
</tr>
<tr>
<td>2. 32-37</td>
<td>38.6</td>
<td>&lt;0.001</td>
<td>7</td>
</tr>
<tr>
<td>3. 28-32</td>
<td>39.4</td>
<td>&lt;0.001</td>
<td>22</td>
</tr>
<tr>
<td>4. &lt;28</td>
<td>39.9</td>
<td>&lt;0.001</td>
<td>11</td>
</tr>
</tbody>
</table>

ABT = arterial blood temperature in °C. paCO₂ = partial pressure of carbon dioxide in arterial blood sample in mmHg. p value for comparison of values between different temperature groups. Sample size = 62 arterial blood gas samples separated into 4 temperature groups.

RESULTS

There was a positive correlation between the p₂CO₂ and ABT. The best fit of the relationship between the p₂CO₂ and ABT according to their routine practice. The p₂CO₂ and ABT were recorded at the time of arterial blood gas sampling from the arterial line filter purge. The sample was immediately analyzed at 37°C on a blood gas system. All instrumentation was calibrated according to the manufacturer’s instructions.

The data was analyzed using a commercially available statistical graphics system. The regression signature was generated by graphing the p₂CO₂ and ABT. The blood gas samples were then divided into four ABT groups, (<28, 28-32, 32-37, and >37°C) and the paCO₂ values within the groups were analyzed using a two sample t-test.
Figure 1
\(p_{e\text{CO}_2}\) vs. Arterial Blood Temperature.
Exponential regression of observed capnograph values with respect to arterial blood temperature.

\[
\begin{align*}
\text{Arterial Blood Temperature (°C)} & \\
\text{P_{e\text{CO}_2} (mmHg)} & \\
20 & 25 & 30 & 35 & 40
\end{align*}
\]

was an exponential regression which had a correlation coefficient of 0.98 (Figure 1). The \(p_{\text{aCO}_2}\) was controlled within normal limits during the study period (Table 1). There was no statistical difference between \(p_{\text{aCO}_2}\) values in the four ABT groups (\(p<0.001\)) (Table 2).

DISCUSSION

The control of ventilation is important in the regulation of the respiratory component of the acid-base system. Intermittent sampling for blood gas analysis is recognized as the standard method of analysis in the operating room. However, a real time, in-line, blood gas and electrolyte monitor that was accurate, inexpensive and easy to use, would be ideal. Such devices are available but may be cost prohibitive in centers that have a dedicated blood gas laboratory in the operating room. Oxygenator exhaust capnography is not a replacement for either laboratory blood gas analysis or in line blood gas monitoring but a useful adjunct to both. After learning the regression signature of an oxygenator, the capnograph becomes a useful tool and safety device for the perfusionist.

Developing the regression signature for an oxygenator simply involves noting the \(p_{e\text{CO}_2}\) from the capnograph along with the ABT from the perfusion console and relating it to the \(p_{\text{aCO}_2}\) from the blood gas analysis. The relationship can be elucidated by graphing the \(p_{\text{aCO}_2}\) and the \(p_{e\text{CO}_2}\) values against the ABT (Figure 2).

Since the regression signature of an oxygenator is a function of the \(p_{\text{aCO}_2}\), the perfusionist may then better control the ventilation of the oxygenator after becoming familiar with the regression signature. Deviation from the normal \(p_{e\text{CO}_2}\) at a given ABT may help diagnose the failure to properly ventilate the oxygenator. Hypoventilation is indicated if the \(p_{e\text{CO}_2}\) is above the regression line at the patient's ABT. Conversely, hyperventilation is indicated if the \(p_{e\text{CO}_2}\) is below the regression line at the patient’s ABT. Most capnographs have an oxygen analyzer which also can be used as a safety device for monitoring the exhaust oxygen concentration as it exits the oxygenator.

This regression signature for the Monolyth was produced with data from the first twenty-six patients on whom the oxygenator was employed at our institution. The mean \(p_{\text{aCO}_2}\) of 39.0 with a standard deviation of 2.5 mmHg was observed, and there was no statistical difference between the \(p_{\text{aCO}_2}\) values at different arterial blood temperatures. It has been our experience that the ability to control the ventilation of the oxygenator using capnography can be rapidly achieved, and the variance in ex-
pected $\text{paCO}_2$ during CPB decreased with practice.

Oxygenator capnography is an inexpensive and accurate method to aid in the control of oxygenator ventilation during CPB. Capnography was used clinically during this study to direct the control of alpha-stat ventilation for the Monolyth membrane oxygenator. After learning the relationship of $\text{paCO}_2$, $\text{PeCO}_2$, and ABT for a specific oxygenator, oxygenator capnography allows precise regulation of $\text{paCO}_2$ at all temperatures.

REFERENCES