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Comparison of Venous Oxygen Partial Pressure (PvO2) and Oxygen Saturation (SvO2) in Hypothermic Blood Flow Control

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Abstract

Mixed venous oxygen content is commonly used to determine the adequacy of oxygenation during cardiopulmonary bypass (CPB). Due to the shift in the oxyhemoglobin disassociation curve during hypothermia, it is unknown whether PvO2 or SvO2 is the best indicator of adequate perfusion. The purpose of this study was to determine if there were any differences in blood flow, calculated base deficit, total fluids, hematocrit and oxygen consumption for dogs in the following two groups: PvO2 between 35–45mmHg and SvO2 between 65–75%. Blood flow was managed in fourteen animals randomly assigned to the PvO2 and SvO2 group during hypothermic CPB. PvO2 management required significantly higher blood flows and total fluids (p<0.05). Hematocrit was significantly higher in the SvO2 group (p<0.05). No differences were detected between the two techniques in base deficit or oxygen consumption (p>0.4). These results suggest that in the canine model SvO2 monitoring during hypothermic CPB is a better indicator of tissue perfusion because of lower blood flows, fluid requirement, and higher hematocrits.

Introduction

There have been many opinions on managing cardiopulmonary bypass (CPB) blood flow during hypothermia. Optimum hypothermic blood flow rates have been suggested to be between 2.3 and 2.5 L/min/m².1,2,3 Stanley and Isern-Amaral reported the use of mixed venous oxygen content to determine optimum blood flow during CPB.4 This idea assumes that a normal mixed venous oxygen content is indicative of a normal venous capillary oxygen content. Normal venous oxygen content is 15 ml/100ml where approximately 98% of the oxygen is bound to hemoglobin with the remainder in solution. A venous blood saturation of 65 to 75% and a venous PO2 of 35 to 45 mmHg will usually indicate a normal content, but a shift to the left of the oxyhemoglobin disassociation curve due to hypothermia, increased pH, decreased pCO2, and increased 2,3-DPG levels can change this relationship.5,6,7 Several studies have reported that a normal venous oxygen partial pressure (PvO2) is the best indicator for adequate oxygen supply to the tissues during hypothermia.4,8 It has also been reported that monitoring venous oxygen saturation (SvO2) is the optimal method of managing hypothermic perfusion blood flow rates.9,10,11

The purpose of this study was to investigate if any significant differences existed in blood flow, calculated base deficit, oxygen consumption, fluid balance and hematocrit when hypothermic blood flow rates are managed to achieve normal SvO2 versus normal PvO2. This study will also evaluate the accuracy of two in-line devices used to monitor PvO2 and SvO2.

Materials and Methods

Fifteen adult mongrel dogs (18 to 35kg.) were treated in accordance with the “Medical University of South Carolina Guide For the Care and Use of Laboratory Animals.” The dogs were anesthetized with pentobarbital (30mg/kg.), intubated and placed on a ventilator. A mid sternotomy and bilateral femoral artery cutdown were performed. The right femoral artery was used for arterial blood pressure measurement and sampling whereas the left femoral was used for arterial cannulation. The dogs were given a loading dose of 300 U/kg of beef lung heparin and the right atrial appendage was cannulated with a dual stage venous

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cannula for venous drainage into the CPB circuit. Activated clotting times were maintained at 300 seconds or greater with supplemental heparin.

Each cardiopulmonary bypass circuit consisted of a Bentley 10 Plus bubble oxygenator,* Bard unfiltered cardiotomy, b ½ × ½ inch PVC tubing, a, a roller pump and a Sarns Cooler/Heater. SvO2 and SvO2 were evaluated with a Cardiomet 1000® connector and a Bentley Oxysat OTC cell, respectively. An additional Cardiomet 1000 connector was inserted in the arterial line. The Bentley Oxysat sensor was checked and the Cardiomet 1000 sensors calibrated both per manufacturer recommendation. Esophageal, rectal, arterial and venous temperatures were monitored. The circuit was primed with 1000 ml lactated Ringers, 500ml6% hetastarch and 1000u beef lung heparin then circulated and warmed to 37 centigrade until cannulation.

Prior to bypass, arterial blood gases were drawn every 30 minutes and run through a Radiometer ABL4 blood gas analyzer. The calculated base deficit was corrected with sodium bicarbonate utilizing the formula:

\[(0.3 \times \text{kg} \times \text{Base Deficit})/2\]

Cardiopulmonary bypass was initiated at 80 to 100 ml/kg/min. The mean arterial blood pressure was maintained at 50 to 80 mmHg with pentobarbital and phenylephrine hydrochloride. Arterial pCO2 was maintained at 35–45 mmHg using oxygen gas flow and arterial oxygen partial pressure (PaO2) was maintained between 150 and 300 mmHg adjusting the pO2 controller of the oxygenator. Ten minutes after initiating bypass an arterial blood gas was drawn and corrected if necessary. Following stabilization of the initial sample no further base deficits were corrected. Each animal was then cooled to 25 degrees C esophageal. Once temperatures equilibrated arterial and venous blood gases, venous oxygen saturation measured with an American Optical Oximeter and hemal-tocrits were drawn every 15 minutes. PaO2, PvO2, SvO2, blood flow rate, and additional fluid administration were recorded every 15 minutes. After one hour of hypothermia the dog was rewarmed to a rectal temperature of 35 degrees C and bypass terminated.

The 15 dogs were randomly assigned to one of two groups prior to lab. In group I, blood flows were managed by maintaining a PVO2 of 35 to 45mmHg. In group II blood flows were managed by maintaining a SvO2 of 65 to 75%. These criteria were maintained for each group except for allowing the minimum flow to be 40ml/min/kg and the maximum 120ml/min/kg.

A Student’s t-test was performed on the mean difference (p < 0.05) in blood flow, fluids required, calculated base deficit, oxygen consumption and hematocrit. Correlation coefficients were calculated between the Cardiomet 1000 and ABL PaO2's, Cardiomet 1000 and ABL PVO2, and Bentley Oxysat and American Optical SvO2.

**Results**

Data from one dog was excluded due to pulmonary emboli related to filarias infestation resulting in seven animals in each group.

The mean and standard error of the mean (SEM) of the PVO2 using the Cardiomet 1000 and the SvO2 using the Oxysat were 38.1mmHg ± 1.1 and 76.3% ± 0.7, respectively. Table 1 is a summary of the data collected for both groups. The blood flow index and fluids required were significantly higher in the PVO2 group (Figure 1 and Figure 2). Hematocrit was significantly higher in the SvO2 group (p < 0.0001). No other significant differences were noted in the data.

The American Optical Oximeter and the Bentley Oxysat SvO2's during hypothermia were significantly correlated during hypothermia (p < 0.01, Figure 3). The Radiometer ABL4 and the Cardiomet 1000 PaO2 values were significantly correlated (p<0.05, Figure 4). PVO2 measured by the ABL4 and the Cardiomet 1000 were positively associated (r = .32, p < 0.01).

**Discussion**

Data from this study suggests that the management of hypothermic blood flows by in-line SvO2 monitoring versus in-line PVO2 monitoring does not provide the same results in the model used in this study. The

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<td>Parameters measured during hypothermia using PVO2 and SvO2 Monitoring</td>
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<tr>
<td><strong>PVO2</strong></td>
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<td>Fluid Requirement (ml)</td>
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Data presented as Mean ± SEM, p values reported are differences between the two groups.
Blood Flow Index (ml/min/m²)

$102 \pm 6 \ (p > 0.0001)$

$59 \pm 4$

Figure 1: Blood flow for PV0₂ and SV0₂ monitoring during hypothermia. Blood flows were significantly higher in the PV0₂ group.

Fluid Requirement (ml)

$1628 \pm 376 \ (p = 0.01)$

$414 \pm 179$

Figure 2: Fluid requirement for PV0₂ and SV0₂ monitoring. Fluid requirement was significantly higher in the PV0₂ group.

Sv0₂ group required significantly less blood flow during hypothermia and significantly less additional fluid.

A normal mixed venous oxygen content is a good indicator of adequate oxygen supply to the tissues. However, this measurement cannot assess oxygen consumption of the individual tissues. Continuous venous content measurement which requires a hemoglobin value in order to be calculated is not yet available for in-line use during cardiopulmonary bypass.

The question arises, whether PV0₂ or SV0₂ monitoring is the best method of determining optimal blood flow. If the PV0₂ method is used, and since pO₂ is the driving force to the tissues, PV0₂ should be maintained between 35-45mmHg. The SV0₂ method dictates that normal venous saturations of 65 to 75% should be maintained since 98% of the blood’s oxygen carrying capacity comes from the hemoglobin. Since both parameters correspond to each other in the normal oxyhemoglobin curve, the two methods should provide similar results although changes in tissue oxygen uptake may be reflected sooner in PV0₂ than SV0₂. During hypothermic bypass the oxyhemoglobin curve shifts upward and to the left causing normal PV0₂s to correspond to higher SV0₂s and normal SV0₂s corresponding to lower PV0₂s. The increased blood flow required to maintain normal PV0₂ may have also contributed to the increased fluid requirement since high blood flow during bypass is associated with increased tissue water content. The increased fluid requirement in the PV0₂ group may have also caused the decreased hematocrit in that group. As a result, this study demonstrated that differences in CPB management using these two methods will occur.

No significant difference occurred in oxygen consumption during hypothermia for both groups which...
suggests the oxygen uptake of the tissues did not increase although the \( {PvO_2} \) group had higher relative blood flows than the \( {SvO_2} \) group. Base deficits at the end of bypass were compared in the two groups in order to determine if arterial venous shunting with lactic and pyruvic acid production from anaerobic metabolism had occurred. No difference was detected between the groups.

The two in-line devices, the Bentley Oxysat and the CardioMet 1000 readings were found to be highly correlated with the American Optical Oximeter and Radiometer ABL4 blood gas analyzer, respectively. During the initial studies, the CardioMet sensors appeared to be malfunctioning possibly because of the age of the probes. This may explain the lower correlations found in the CardioMet 1000 and the several outlying points (Figure 4). This study agrees with previous studies finding both the Bentley Oxysat and the CardioMet 1000 to be reliable devices.

In summary, \( {PvO_2} \) monitoring during hypothermia resulted in higher blood flows, increased fluid requirements and decreased hematocrit. Results from this study suggest that \( {SvO_2} \) monitoring is a better method for hypothermia blood flow management.

Acknowledgement

This study is the last project of the late Mr. James Dearing. His idea for this project was the result of his always present desire to further perfusion knowledge. Jim’s procurement of an AmSECT research grant in 1986 allowed us to complete this study for him.

References