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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 PvO_2 or SvO_2 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: PvO_2 between 35–45mmHg and SvO_2 between 65–75%. Blood flow was managed in fourteen animals randomly assigned to the PvO_2 and SvO_2 group during hypothermic CPB. PvO_2 management required significantly higher blood flows and total fluids ($p<0.05$). Hematocrit was significantly higher in the SvO_2 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 SvO_2 monitoring during hypothermic CBP 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 PO_2 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 pCO_2, and increased 2,3-DPG levels can change this relationship.[5,6,7] Several studies have reported that a normal venous oxygen partial pressure (PvO_2) 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 (SvO_2) 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 SvO_2 versus normal PvO_2. This study will also evaluate the accuracy of two in-line devices used to monitor PvO_2 and SvO_2.

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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 midsternotomy 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 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,[a] Bard unfiltered cardiotomy,[b] 3/8 × 3/32 inch PVC tubing,[a], a roller pump and a Sarns Cooler/Heater[c]. PvO_2 and SvO_2 were evaluated with a Cardiomet 1000[d] connector and a Bentley Oxysat OTC Cell,[a] 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, 500ml 6% 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.[e] The calculated base deficit was corrected with sodium bicarbonate utilizing the formula:

$$(0.3 * kg * \text{Base Deficit})/2$$

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 pCO_2 was maintained at 35–45 mmHg using oxygen gas flow and arterial oxygen partial pressure (PaO_2) was maintained between 150 and 300 mmHg adjusting the pO_2 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 Oximter[f] and hematocrits were drawn every 15 minutes. PaO_2, PvO_2, SvO_2, 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 PvO_2 of 35 to 45mmHg. In group II blood flows were managed by maintaining a SvO_2 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 PaO_2s, CardioMet 1000 and ABL PvO_2s, and Bentley Oxysat and American Optical SvO_2s.

a Baxter Bentley, Irvine, CA 92714
b William-Harvey, Billerica, MD 01821
c Sarns, Ann Arbor, MI 48106
d BioMedical Sensors, Inc., Kansas City, MO 64153
e Radiometer, Westlake, OH 44145
f American Optical, Buffalo, NY 14240

Results

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

The mean and standard error of the mean (SEM) of the PvO_2 using the CardioMet 1000 and the SvO_2 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 PvO_2 group (Figure 1 and Figure 2). Hematocrit was significantly higher in the SvO_2 group ($p < 0.0001$). No other significant differences were noted in the data.

The American Optical Oximeter and the Bentley Oxysat SvO_2s during hypothermia were significantly correlated during hypothermia ($p < 0.01$, Figure 3). The Radiometer ABL4 and the CardioMet 1000 PaO_2 values were significantly correlated ($p<0.05$, Figure 4). PvO_2 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 SvO_2 monitoring versus in-line PvO_2 monitoring does not provide the same results in the model used in this study. The

Table 1

Parameters measured during hypothermia using PvO2 and SvO2 Monitoring

	PvO2	SvO2	p Values
Blood Flow Index (ml/min/m2)	102 ± 6	59 ± 4	0.0001
Fluid Requirement (ml)	1628 ± 376	414 ± 179	0.01
Base Deficit	4.8 ± 0.8	5.7 ± 0.9	0.48
O2 Consumption Index (ml/min/kg)	1.59 ± 0.05	1.61 ± 0.08	0.80
Hematocrit (Percent)	21.9 ± 0.8	26.9 ± 1.2	0.0001

Data presented as Mean ± SEM, p values reported are differences between the two groups.

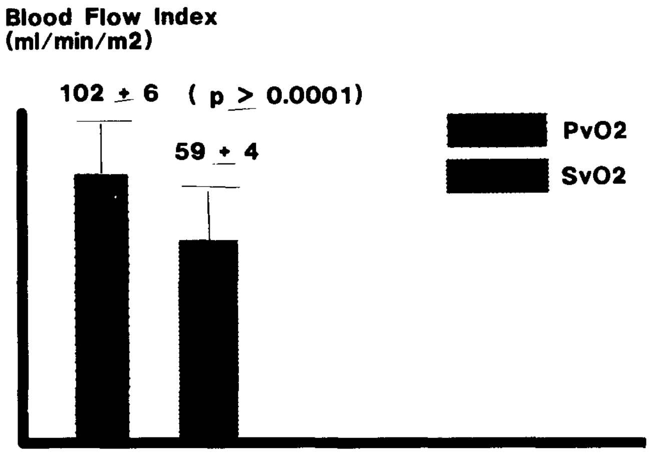

Figure 1: Blood for PvO_2 and SvO_2 monitoring during hypothermia. Blood flows were significantly higher in the PvO_2 group.

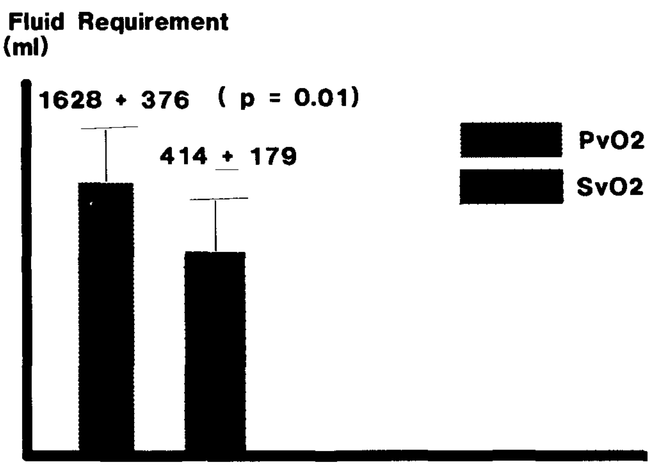

Figure 2: Fluid requirement for PvO_2 and SvO_2 monitoring. Fluid requirement was significantly higher in the PvO_2 group.

SvO_2 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.[11] 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 PvO_2 or SvO_2 monitoring is the best method of determining optimal blood flow. If the PvO_2 method is used, and since pO_2 is the driving force to the tissues, PvO_2s should be maintained between 35–45mmHg. The SvO_2 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

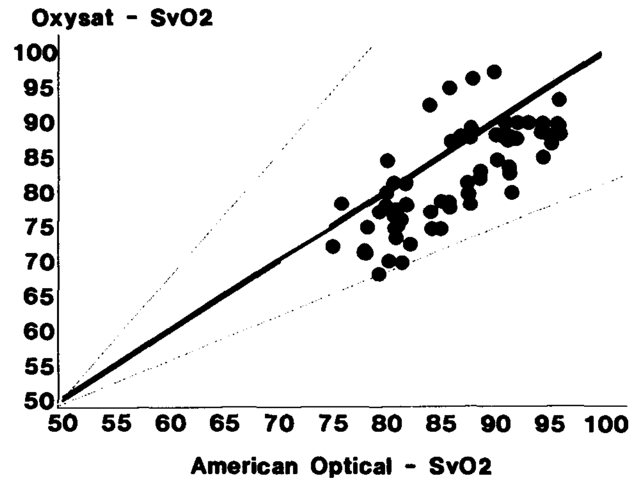

Figure 3: Scatter diagram of American Optical Oximeter SvO_2 versus Bentley Oxysat SvO_2 values. The solid line is the line of identity and the dashed lines represent 20 percent variability ($r = 0.75$, $p < 0.01$).

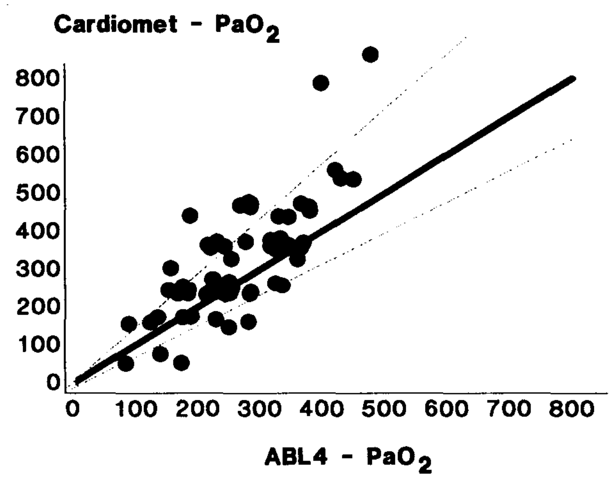

Figure 4: Scatter diagram of Radiometer ABL4 PaO_2 versus CardioMet 1000 PaO_2 values. The solid line is the line of identity and the dashed lines represent 20 percent variability ($r = -0.78$, $p < 0.01$).

provide similar results although changes in tissue oxygen uptake may be reflected sooner in PvO_2 than SvO_2.[8,12] During hypothermic bypass the oxyhemoglobin curve shifts upward and to the left causing normal PvO_2s to correspond to higher SvO_2s and normal SvO_2s corresponding to lower PvO_2s.[13,14] The increased blood flow required to maintain normal PvO_2 may have also contributed to the increased fluid requirement since high blood flow during bypass is associated with increased tissue water content.[15] The increased fluid requirement in the PvO_2 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.[16] 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 analyer, 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.[10,17]

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.

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