Original Article

The Relationship Between Oxygen Transfer and FIO_2 in a Clinical Study of the Affinity™ Hollow Fiber Oxygenator

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ABSTRACT

On-line computation of body oxygen consumption ($\dot{V}O_2$) was performed in twelve (n=12) cardiac surgical patients utilizing cardiopulmonary bypass. Two in-line monitors, the CDI 400™ and CDI 100™ were interfaced with a personal computer. Arterial oxygen partial pressure, saturation and temperature from the CDI 400™ and venous saturation and hemoglobin values from the CDI 100™ enabled a real time computerized $\dot{V}O_2$ calculation. Paired $\dot{V}O_2$ and fractions of inspired oxygen (FIO_2) values made it possible to plot an oxygen transfer equation (OTE) for the AVECOR Affinity™ hollow fiber oxygenator. Regression analysis of 124 $\dot{V}O_2$-FIO_2 pairs established the following relationship: $\dot{V}O_2 = 368.4 * FIO_2 - 15.6$, with a correlation of 0.89 ($p<0.001$). This regression line presented as an OTE-plot suggests that the Affinity™ oxgenator is capable of transferring approximately 350 ml/min of oxygen at an $FIO_2 = 1.0$. In conclusion, on-line CPB-monitoring interfaced with a personal computer may be used for real time $\dot{V}O_2$ - calculations and to establish an oxygen transfer equation of a given oxygenator.

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INTRODUCTION

On-line blood gas monitoring during cardiopulmonary bypass (CPB) is a well established technique (1, 2). Computerized blood gas data analysis offers a still new dimension. This study demonstrates how continuous arterial-venous data sampling may be used to calculate real time body oxygen consumption ($\dot{V}O_2$) and applied in establishing an oxygen transfer equation (OTE) (3) for the Avecor Affinity™ hollow fiber oxygenator (4).

MATERIALS AND METHODS

Twelve (n=12) patients scheduled for various cardiac procedures requiring cardiopulmonary bypass (CPB) were included (Table 1). The CPB circuit was comprised of a Sarns® System 9000 heart-lung machine [a], PVC-tubing, and an Avecor Affinity™ hollow fiber oxygenator with an open hardshell venous reservoir [b]. Moderate hypothermic (31.4±1.3°C) CPB was utilized in all cases. Blood flow was regulated to maintain a venous oxygen saturation (SvO_2) exceeding 70 percent. Acid-base management followed an alpha-stat regime.

Blood Gas Monitoring

Continuous sampling of blood gas data from both arterial and venous lines was accomplished by using two in-line blood gas monitors, the CDI 400™ and the CDI 100™ respectively [c]. Both CDI monitors were set-up and calibrated as prescribed by the manufacturer.

The CDI 400™ was set at 37°C to measure the arterial oxygen partial pressure (paO_2), arterial saturation (SaO_2) and temperature. SaO_2 was attained by placing a CDI 400™ venous sensor in the arterial line position. Venous blood gas data was obtained from the CDI 100™ giving values for venous oxygen saturation (SvO_2) and hemoglobin (Hb). Venous oxygen partial pressure (pvO_2) was set to 45 mmHg, as this information is not available from the CDI 100. The arterial and venous blood gas data (Table 2) were interfaced with a personal computer. Pump flow (Q) and fraction of inspired oxygen (FIO_2) were entered to the computer keyboard when indicated. Oxygen consumption was computed every 30 seconds using the modified formula of Fick (5), where a and v denote the arterial and venous oxygen content respectively:

$$\dot{V}O_2 = \text{Diff } Q(a-v)$$
$$a = (1.39 * Hb * SaO_2) + (paO_2 * 0.0031)$$
$$v = (1.39 * Hb * SvO_2) + (pvO_2 * 0.0031)$$

Data collection for the OTE calculation was recorded when conditions for pump flow, temperature and arterial pO_2 were stable for more than three minutes. PaO_2 was maintained below 150 mmHg in order to minimize the transport of dissolved oxygen.

A correlation plot between FIO_2 and $\dot{V}O_2$ was performed using a statistical software package[d], where the regression line, calculated with least square regression method, illustrates the oxygen transfer equation of the Affinity oxygenator.

Table 1: Patient Demographics

Characteristics (n=12)	Mean	± SD	Numbers
Age	68	3.3	
Aortic Cross-Clamp Time (minutes)	57	6.5	
CPB Time (minutes)	103	9.8	
CABG			10
Valve Replacements			2

Table 2: Computer Interfaced Blood Gas Data

Monitor Device	Label	
CDI 100	Hb	g/dl
	SvO2	%
CDI 400	PaO2	kPa
	SaO2	%
	Temp	°C

RESULTS

The OTE of the Affinity™ oxygenator is based on 124 measurements in 12 patients. Regression analysis revealed the following relationship between oxygen consumption and fraction of inspired oxygen: $\dot{V}O_2 = 368.4 * FIO_2 - 15.6$. The correlation coefficient reached 0.89 ($p<0.001$) (Figure 1).

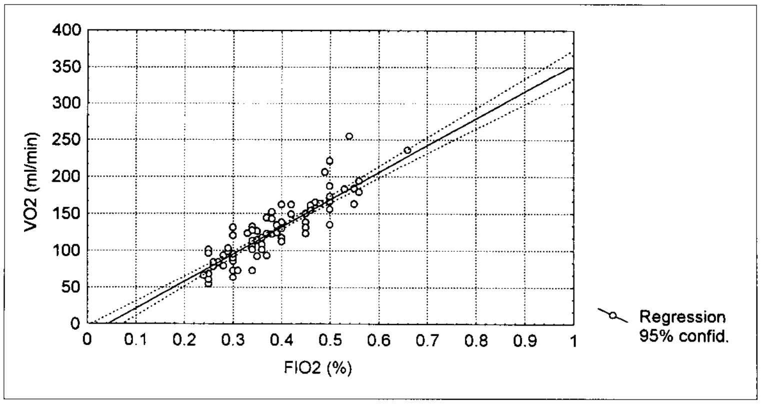
Extrapolation of the regression line indicates that the Affinity™ oxygenator is capable of transferring approximately 350 ml/min of oxygen at $FIO_2 = 1.0$.

DISCUSSION

On-line monitoring in CPB can be used to calculate oxygen consumption and to illustrate oxygenator performance. Oxygenator evaluation as described by Fried et al. (3) would clas-

a Sarns, 3M Health Care, Ann Arbor, MI 48105
b Avecor Cardiovascular Ltd, Glasgow, Scotland, UK
c CDI, 3M Health Care, Ann Arbor, MI 48105
d Statistica, StatSoft, Inc.

Figure 1: The computerized oxygen transfer slope of the Affinity Hollow Fiber Oxygenator (n=124). Correlation r=0.89



sify a particular oxygenator as normal or deviating from a given norm. Future software progress, with information of different oxygenators' oxygen transfer profile, would supply the perfusionist with instant diagnostic feedback. The safety perspective is attractive, as oxygenator function then could be judged on facts rather than on sudden decision making (6).

We used the on-line $\dot{V}O_2$ technique to determine the oxygen transfer equation (3) of the Affinity™ hollow fiber oxygenator. The oxygen transfer rate at FIO_2=1.0 by extrapolation was close to 350 ml/min. However, the obtained OTE equation is merely based on values where $\dot{V}O_2$ is below 200 ml/min and sub maximal FIO_2 settings. Higher levels were difficult to attain, because data collection had to be terminated before release of the aortic cross clamp. Blood flow through the human lung would bias the $\dot{V}O_2$ determination in the extracorporeal circuit. The true clinical maximum oxygen transfer rate is still to be evaluated and preferably based on a full FIO_2 range.

Our model of $\dot{V}O_2$ measurement did not take into consideration the variation in pvO2, as this was set to a constant (45 mmHg). However, this will have little or no clinical influence on the $\dot{V}O_2$ calculation, especially when paO2 was controlled to 150 mmHg.

The need for $\dot{V}O_2$ determinations during CPB is poorly investigated. We know from experimental data that oxygen demand is related to blood flow (7). $\dot{V}O_2$ increases with cardiac output up to a defined maximum. Utilization of oxygen consumption to peer blood flow requirements during CPB is an interesting concept.

On-line monitoring of oxygen consumption is limited by its lack of reliability. The CDI 100™ tends to overestimate hemoglobin, whereas saturation levels are undervalued (8). This would implicate a higher oxygen arterial transport as well as a higher oxygen extraction. As a consequence, the $\dot{V}O_2$ calculation may be to some extent optimistic. The CDI 400™ in the arterial position should transfer acceptable readings for both pO_2 and SaO_2 measurements (9).

The communication port of the CDI 100™ updates its information once every 30 seconds in combination with a partially interactive system resulting in delayed response time. In future development, one single monitor would be preferred handling all data flow automatically. If a single monitor were developed to collect and analyze the data automatically the delay would be reduced.

In summary: a computerized on-line model for $\dot{V}O_2$ determination during CPB may be applied in calculating the oxygen transfer equation for a given oxygenator. However, for routine clinical use it needs to be refined.

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