

Case Report

Case Study: Use of Two Parallel Oxygenators in a 159 Kilogram Patient during Normothermic Cardiopulmonary Bypass

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ABSTRACT

There have been few reports describing the perfusion of large patients with relevance to oxygen transfer and oxygen consumption (1,2). This report describes the technique of two oxygenators connected in parallel on a 33 year old male who presented to the operating room for repair of an acute dissecting type A ascending aortic aneurysm. The patient's weight was 159 kg, height 189 cm, and BSA 2.88 m². The calculated blood flow, using a cardiac index of 2.4 L/min/m² was 6.9 L/min. The theoretical oxygen consumption was calculated as 375 ml/min. The oxygen transfer of the oxygenator is rated at 350 ml/min at a flowrate of 6 L/min. To deal with the possibility of inadequate oxygenation in this large patient, due to insufficient oxygenator surface area, the decision was made to use a second oxygenator in parallel.

The pump was set-up in the usual fashion and the second oxygenator was connected into the existing circuit and de-aired. It was then clamped out of the circuit, ready for future use. Cardiopulmonary bypass was instituted via femoral arterial and right atrial cannulation. Standard normothermic bypass and warm cardioplegia techniques were used after initiation of cardiopulmonary bypass. Venous oxygen saturation indicated insufficient oxygenation within three minutes on pump. The second oxygenator was immediately brought into use resulting in normal physiologic levels within ninety seconds. The patient underwent a successful Cabral procedure, with a total cardiopulmonary bypass time of one hundred and ten minutes. There were no problems separating the patient from bypass.

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INTRODUCTION

Tissue oxygenation depends on the volume of oxygen delivered compared to the volume of oxygen consumed by the tissues (3). This supply/demand balance depends on hemoglobin (Hgb) concentration, the percentage of Hgb saturated with oxygen in arterial blood (SaO_2), cardiac output (CO), oxygen consumption (VO_2), and the affinity of Hgb for oxygen (p50) (3). The ability to adequately oxygenate a patient on cardiopulmonary bypass (CPB) depends not only on the above factors, but also on the physical characteristics of the perfusion equipment.

Membrane oxygenators have a fixed oxygen transfer rate (4) and will transfer a specific amount of oxygen to the blood on each pass through the oxygenator. The higher the blood flowrate, Hgb concentration, and fraction of inspired oxygen (FiO_2), the greater the oxygen transfer rate. Membrane oxygenator transfer capacities are calculated on the basis of arterial-venous oxygen differences using the following formula:

$$\text{O}_2 \text{ transfer} = (\text{SaO}_2 - \text{SvO}_2)(1.34 * \text{Hgb})(10)(\text{blood flow rate L/min}) \quad (4)$$

This formula may be used to calculate the flowrates necessary to deliver adequate oxygen to the tissues if the patient's oxygen consumption is known or to calculate the capacity of an oxygenator to transfer oxygen (4). Arterial blood gases reveal information about gas transfer capabilities of the oxygenator whereas the venous blood gases reveal information about the oxygen extraction of the patient (4). An inadequate perfusion rate may be reflected by a metabolic acidosis. A pvO_2 of < 25 mmHg at normothermia ($\text{SvO}_2 < 50\%$) indicates that the tissues are extracting more than the usual amount of oxygen from the blood flow available to them (4). Increasing the perfusion flowrate will improve the venous saturations. However, there are limitations to the pump flow and it is dependent on several factors such as the size of the arterial cannula, size and position of the venous cannula, and arterial line pressures.

The surface area of a membrane oxygenator is constant and product information provides guidelines on the use of the membrane. The surface area of the Cobe CML^a is suitable for patients up to 110 kg weight*. The surface area of the oxygenating unit can be increased by adding another unit in parallel. The oxygen transfer of a single membrane is given in terms of rated blood flow. For the Cobe CML this is 350 ml/min at a flowrate of 6 L/min. The oxygen demand of the patient can be calculated by assuming an average oxygen consumption of 130 ml/min/m² (5). The oxygen demand of the patient may be decreased with anesthesia and/or hypothermia. The standard technique in this particular hospital is normothermic bypass with warm cardioplegia, therefore oxygen requirements will not be reduced at all throughout the entire procedure. Given the severity of the case and possible complications associated with aortic dissections, the means to cool the patient were available.

CASE REPORT

The patient, a 33 year old male, presented to the operating room with a primary diagnosis of acute type A ascending aortic aneurysm. His previous history was significant for hypertension.

When the patient arrived in the operating room, his large size was noted. The patient's chart had indicated a weight of 159 kg, height 189 cm and BSA 2.88 m². The obvious concern was the capability of the oxygenator to adequately oxygenate such a large patient. It was decided by the perfusion team to incorporate another membrane oxygenator as a safety measure. The calculated flows using a cardiac index of 2.2-2.4 L/min/m² and 40-60 ml/kg/min were 6.3-6.9 L/min and 6.4-9.5 L/min respectively. His pre-bypass cardiac output was 6.1 L/min. The oxygen demand of the patient was calculated as 375 ml/min. The patient was anesthetized, surgery was begun and preparations for CPB commenced. A heparin dose of 45000 IU was administered as per protocol resulting in an ACT of 467 seconds. Due to the nature of the operation, the femoral artery was chosen as the site of arterial cannulation. Because of the small size of the femoral artery, a 22 Fr. Bard^b cannula was chosen. A 51 Fr. two stage Sarns^c venous cannula was inserted in the right atrium. The patient was placed on CPB with an initial flowrate of 5.6 L/min and an arterial pressure of 70 mmHg, resulting in an arterial line pressure of 240 mmHg(post-membrane). The patient was maintained at 37 degrees centigrade. The venous saturations were measured by a Bentley^d SM-0200 oxygen saturation monitor. After three minutes on CPB, the venous saturations dropped to 38%. Blood samples were drawn at this time and sent to the lab. The pump flows were increased to 6.4 L/min with no subsequent improvement in venous saturation. The second membrane was incorporated after four minutes on bypass and the venous saturation recovered to 60% within ninety seconds. Both membranes were utilized throughout the entire procedure with no complications. The patient was weaned from bypass successfully and sent to the cardiovascular ICU. The post-operative course was unremarkable.

CARDIOPULMONARY BYPASS CIRCUIT

The initial bypass circuit consisted of a single Cobe CML Excel microporous polypropylene membrane oxygenator. The membrane surface area is 3.0 m² with a rated blood flow of 0.5-8.0 L/min. The membrane priming volume is 470 ml. An integral hard shell venous reservoir is part of the CML Excel with a capacity of 3600 ml.

The venous return line was 1/2 inch in diameter and the

- a Cobe Laboratories, Inc., Lakewood, CO 80215
*Cobe Laboratories Inc. Product Specifications 421-200-038
- b C.R. Bard Inc., Billerica, MA 01822
- c Sarns, 3M Ann Arbor, MI 48106
- d Bentley Laboratories Inc., Irvine, CA 92713

Table 1

Time (min)	Gas Flow (L/min)	FiO ₂	pH	pCO ₂ (mmHg)	pO ₂ (mmHg)	BE	venous saturation (%)	pvO ₂ (mmHg)	HCT	perfusion Flowrate (L/min)
pre	—	1	7.49	39	499	—	—	—	—	6.1
3	5	1	7.40	42	142	1.2	38	—	26	5.6
8	9	1	7.45	37	209	-2.3	60	36	—	6.4
38	8.5	1	7.44	41	238	4.3	66	39	27	6.4
73	8.5	1	7.44	40	211	3.5	62	38	27	6.4
106	8.5	1	7.42	39	216	2.6	56	38	—	5.9

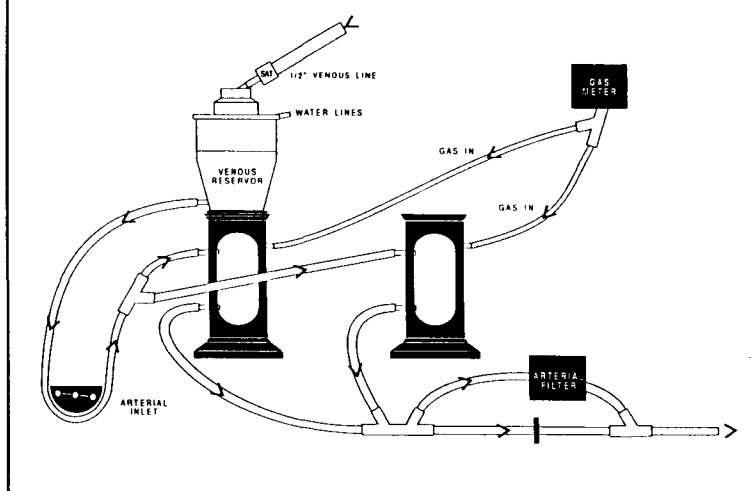
arterial line was 3/8 inch in diameter except for the 1/2 inch boot through the pump head. A Bentley AF1040 arterial line filter^d was used. A Shiley BCD Plus 4:1 cardioplegia set^e was connected into the arterial line at the usual site, just exiting the membrane. The second membrane was used without the integral cardiotomy reservoir. The 3/8 inch line from the pump head was connected to the inlet of both membranes and the outlet of both membranes were connected together to form a single 3/8 inch line to the arterial filter. The gas source was connected to both membranes (Figure 1).

CONDUCT OF PERFUSION

Prior to bypass the second oxygenator was added in parallel to the existing primed circuit. The Cobe CML membrane does not require a CO₂ flush and the ease with which de-airing occurs is very advantageous. The priming volume initially was 2200 ml and 800 ml was added to the system to accommodate priming of the second oxygenator. The final prime consisted of 2800 ml Plasma-Lyte A, 200 ml 25% albumin, and 5000 IU heparin. Once on CPB the gas flow was set at 5 L/min with an FiO₂ of 1.0. Normothermia was maintained with the Sarns^e dual cooler/heater unit only to the primary membrane. The cross clamp was applied after one minute on CPB and cardioplegia administered as per protocol. At three minutes on CPB the venous saturations dropped to 38% and arterial blood gases were drawn. The blood flows were increased to 6.4 L/min with no subsequent improvement in venous saturation. At four minutes on CPB the second oxygenator was incorporated. The clamps were removed from the inlet and outlet of the second oxygenator, so blood flow was directed into both membranes. The gas flow was increased to 9 L/min and the FiO₂ remained at 1.0. The venous saturation recovered to 60% within ninety seconds. The blood samples taken are shown in Table 1.

Figure 1

Circuit setup with second oxygenator in parallel



DISCUSSION

In this particular case the size of the patient was of prime concern. A decision was made to add a second oxygenator in parallel due to the very great possibility of requiring additional surface area support. The greatest demand placed on the membrane oxygenator, occurs when the venous saturations are low, Hgb is high, flows are maximal, and temperature is normothermic. Even though the first paO₂ of 142 mmHg appears acceptable, the ability of the oxygenator to continue saturating this blood would be questionable as the oxygen extraction was very high. Measurement of arterial blood gases indicates how well the membrane oxygenator can perform under various conditions but does not give information about the balance between oxygen demand and oxygen transport (6). However, venous oxygen saturation provides information about the adequacy of the oxygen transport system (6) and can function as an early warning of a decreased oxygen supply or an increased oxygen demand. Since oxygen transport to the tissues is determined by perfusion flowrates, Hgb concentration, and arterial oxygen saturation (7),

e Sorin Biomedical Inc., Irvine, CA 92713

f Baxter Healthcare Corp., Deerfield, IL 60015

a fall in venous saturation to 38% indicates that, either one, or a combination of these parameters are not being met. Since the perfusion flowrate was increased from 5.6 L/min to 6.4 L/min with no subsequent rise in venous saturation, it was hypothesized that the arterial saturation was too low and the second oxygenator was immediately incorporated. An improvement in venous saturation indicated that the demand of the patient was now being met.

The perfusion flowrate of the patient was kept at the highest rate possible, as any decrease led to a fall in venous saturation. Perfusion flowrate, is without a doubt, a very important aspect of the oxygen transport system and can be used to compensate for a low Hgb and/or high oxygen consumption to yield a normal venous saturation. However, given the constraints of the perfusion system, it is not always possible to have optimal perfusion flowrates. In this case, high line pressures and limited venous return were the dictating factors.

During normal daily routine the perfusion circuit rarely changes. In being prepared for possible problems the risk to the patient is reduced dramatically. Patients similar to the example illustrated in this case pose a challenge to the cardiac team and provide an environment for academic discussion and creation of innovative perfusion techniques.

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