Clinical Use of a New Membrane Oxygenator

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Abstract

A new oxygenator, developed by Shiley Laboratories, uses microporous polypropylene membrane material in a parallel plate design. The device has an integral heat exchanger and built-in temperature ports.

The M-2000 oxygenator was used for routine cardiopulmonary bypass (CPB) during open heart surgery on sixteen consenting adult patients. Mean age of the group was 56 years and the mean body surface area was 1.77m^2. One patient had an atrial septal defect repaired, nine had coronary bypass, five had valve replacement and one, a valve replacement with coronary bypass. The average CPB time was 105 minutes.

The circuit was primed with 2000 ml of balanced electrolyte solution and 500 ml of 6% hydroxyethyl starch in 0.9% saline to which 1500 units of heparin had been added.

Average normothermic blood gas values were; p_aO_2=242 mm Hg, p_aCO_2=32.5 mmHg. During hypothermia the temperature corrected mean values were; p_aO_2=155 mm Hg and p_aCO_2=31 mm Hg. Hematological changes observed were hematocrit and hemoglobin concentrations decreased 33% due to dilution. Platelet counts decreased 46%. Plasma hemoglobin values increased by 19.6 mg/dl.

The M-2000 presented no problems to the investigators during this study. It exchanged gases in a satisfactory manner and is gentle in its blood handling properties.

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Introduction

The Medical University of South Carolina was selected as one of three open heart surgery centers to perform Federal Food and Drug Administration (FDA) clinical trials on the new M-2000 membrane oxygenator developed by Shiley Laboratories.[a] After successful completion of the clinical trials, the device received FDA approval and the M-2000 was incorporated into the heart-lung circuit at the Charleston Veterans Administration Medical Center (CVAMC) as the oxygenator of choice.

The purpose of this report is to present the hematological and performance data generated from both the FDA study and the subsequent routine clinical use.

Methods and Materials

The M-2000 oxygenator contains 2.3 m^2 of microporous polypropylene membrane, Z-folded to provide 61 parallel blood and 60 parallel gas compartments. The elements of the Z-folded membrane are kept seperated by the insertion of non-woven polypropylene screens in each gas and blood fold. The screens also aid in oxygen transfer by inducing secondary flow patterns on blood traveling through the device. The parallel plates are encompassed along with an integral venous side heat exchanger in a rigid polycarbonate case. The heat exchanger is composed of six feet of seamless anodized aluminum similar to the heat exchanger in the Shiley S-100A bubble oxygenator.

Venous blood is pumped into the 1/2-inch inlet, past an integral temperature probe and luer-lock port and over the heat exchanger. The blood then

a. Shiley Incorporated, Irvine, CA 92714

passes through the membrane compartment from bottom to top where the gas exchange occurs. Upon exiting the membrane compartment, the blood goes through an arterial manifold containing a temperature probe and a luer-lock port and out the 3/8-inch arterial connector to the patient. The oxygenating and ventilating gas enters the membrane compartment at the top via a 1/4-inch connector and passes, countercurrent to the blood flow, to the bottom of the device where it exits via a 1/4-inch port. The possibility of obstructing gas exhaust is obviated by the placement of four additional small holes on the lateral wall of the gas outlet port. The oxygenator is held in place by a holder that can swivel both vertically and horizontally to aid in assembly and priming.

The CPB circuit in which the oxygenator was used consisted of 1/2-inch PVC tubing returning venous blood to a Sci-Med R-500 reservoir bag[b] held between a Sci-Med compression plate. Blood was pumped from the reservoir via PVC tubing and a roller pump through the M-2000. The oxygenated blood then passed through a Pall model EC 3840[c] arterial line filter to the patient via 3/8-inch PVC tubing. The recirculating line of the R-500 reservoir bag was attached to the luer-lock port on the arterial manifold of the M-2000. A three-way stopcock[d] was attached to the 1/4-inch luer-lock port in the recirculating line for arterial sampling purposes. A three-way stopcock was attached to the luer-lock port on the venous inlet port of the M-2000. A filtered (valve replacements, aneurysmectomies or congenital defects) or nonfiltered (coronary bypass) cardiotomy reservoir[e] with from one to three suction lines, drained into the R-500 reservoir.

This system was primed with 2000 ml of Lactated Ringers (L/R) solution and a solution of 6% hydroxyethyl starch in 0.9% saline (HES)[f] to which was added 1500 units of beef lung heparin unless the calculated on-pump hematocrit would be depressed below 25% or the calculated[1] on pump colloid osmotic pressure (COP) would be depressed below 10 mmHg. Three patients received a prime of 500 ml HES and 1500 ml L/R; one, a prime in which 200 ml of 25% albumin replaced 200 ml of L/R; one, a prime in which 220 ml of packed red cells replaced L/R; and one, a prime in which 440 ml of L/R was replaced by packed red cells.

The CPB protocol called for flow rates of 2.2 liters blood flow per minute (LPM) per m^2 of body surface area (BSA) upon the initiation of CPB. Moderate hypothermia (25-28° C.) was induced in all patients except the one who underwent artrial septal defect (ASD) repair. During the period of hypothermia, blood flow was reduced to 1.6 LPM per m^2 BSA. Following removal of the aortic cross-clamp, rewarming was initiated and blood flow increased during the rewarm period to 2.8 LPM per m^2 BSA.

During all of the clinical CPBs, the oxygenating function was monitored by in-line arterial and venous oxygen saturation monitors.[g] The p_aO_2 was controlled by altering the FiO_2 of the ventilating gas.[h] The ventilating function was monitored by continuous monitoring of the exhaust gas CO_2 concentration.[i] p_aCO_2 was controlled by varying the ventilation rate. The continuous monitoring was supported by frequent blood-gas analysis (BGA).[j] Where required, BGA data were temperature corrected.[2]

Sixteen consenting adult patients were perfused using the M-2000 oxygenator in the FDA trials. A back-up bubble oxygenator was set up and primed prior to CPB in all cases. The CVAMC data were generated from 33 consecutive cases.

Hematology and blood chemistry functions and the frequency of measurement for the FDA trials are summarized in Table 1. Blood and blood product utilization was recorded through the recovery period. For the first five post-operative days, the FDA trial patients were evaluated by the attending surgeon for the following criteria; consciousness, neurological function, renal function, respiratory function, cardiac function and highest daily temperature.

Subjective opinions were obtained from the perfusionist as to the ease of set-up, priming and operation. Finally, blood gas data generated from the CVAMC cases were subjected to regression analysis to determine the precision of control of both p_aO_2 and p_aCO_2 during the hypothermic and normothermic phases of CPB. During the last thirteen cases, the

b. Sci-Med Life Systems, Minneapolis, MN 55441
c. Pall Biomedical Products Corporation, Glen Cove, NY 11542
d. Cobe Laboratories, Lakewood, CO 80215
e. Models Q220F and Q220, Bentley Laboratories, Irvine, CA 92714
f. Hespan, American Critical Care, McGaw Park, IL 60085
g. Oxysat, Bentley Laboratories, Irvine, CA 92714
h. Sechrist Air-Oxygen Mixer, Sechrist Inc., Anaheim, CA 92806
i. Foregger N Tidal CO_2 Monitor #22300, Northwest Oxygen Corp., Chamblee, GA 30341
j. IL Micro 13, Instrumentation Laboratories, Decatur, GA 30025

Table 1
Hematology and Blood Chemistry Intervals

INTERVAL	BASE	ON CPB	15 MIN	MID	END	24 HR	48 HR
RBC	X	X	X	X	X	X	X
WBC	X	X	X	X	X	X	X
PLAS HGB	X	X	X	X	X	X	X
HGB	X	X	X	X	X	X	X
HCT	X	X	X	X	X	X	X
PLAT CT	X	X	X	X	X	X	X
ACT	X	X	X	X	X	X	X
GLUCOSE	X					X	
BUN	X					X	
CREATININE	X					X	
U ACID	X					X	
K+	X					X	
IN PHOS	X					X	
CL−	X					X	
SGOT	X					X	
SGPT	X					X	
LDH	X					X	
ALK PHOS	X					X	
T PROTEIN	X					X	
ALBUMIN	X					X	
BILIRUBIN	X					X	

regression equations were used to set FiO_2 concentrations and to determine ventilation rates.

Results

Patient ages, sizes, CPB times and CPB urine output and operation data are summarized in Table 2. Pertinent blood gas, hematology and blood chemistry data from the FDA trials are summarized in Table 3. There were no other significant variances from previously reported series[3,4] noted during the FDA study. One patient during the FDA trials suffered a transient left hemiparesis which resolved by the fifth post-operative day. Two patients exhibited slight increases in BUN and creatinine levels which normalized by the fifth post-operative day. One patient required prolonged ventilator support for four days but the patient was known to suffer from obstructive pulmonary disease prior to CPB. The remaining FDA patients had benign post-operative courses.

Regression equations relating body size (BSA) to the FiO_2 required to achieve good P_aO_2 (90-150 mmHg) during three phases of the CVAMC clinical procedures follow:

UPON INITIATION OF CPB

$Y = .484X - .125$ $R = .947$

DURING MODERATE HYPOTHERMIA

$Y = .594 - .50$ $R = .914$

UPON REWARMING

$Y = .342 + .155$ $R = .616$

$Y = FiO_2$ required to achieve a P_aO_2 between 90 and 150 mmHg

X = The patients BSA in m^2

Using the equations above the mean $pO_2 \pm$ S.D. at the three intervals during the last thirteen CPB procedures were:

Upon initiation of CPB = 133 ± 22 mmHg

During moderate hypothermia = 107 ± 10

Upon rewarming = 125 ± 13

The perfusionists' subjective evaluation of the ease of operation of the M-2000 was very positive. All felt, after a few experiences, that the device was as easy to set up and prime as a bubble oxygenator. With several case experiences, the time required to set up and prime the system was equivalent to that required for a bubble oxygenator. During one emergency situation, the system was set up, primed, and CPB established in under 20 minutes.

Table 2

FDA Patient Summary

AGE	BSA	CPB TIME	URINE OUTPUT
56.2±17	1.77±.34	105±40	454±421

Operations

CABG	AVR	MVR	CABG+VALUE	ASD
10	3	1	1	1

CVAMC Patient Summary

AGE	BSA	CPB TIME	URINE OUTPUT
58.6±10	1.97±.17	127±37.3	172±78

Operations

CABG	AVR	MVR	CABG+VALUE	CABG+LVAN
23	5	1	2	2

Table 3

M–2000 Results

On CPB

	FiO_2	P_aO_2	QG/QB	P_aCO_2
Hi	1	374	.80	39.9
Lo	.78	106	.66	23.0
Mean	.97	278	.69	30.9
Hypothermia				
Hi	.97	359	.62	36.4
Lo	.60	74	.12	26.0
Mean	.81	155	.35	31.0
Rewarmed				
Hi	.99	292	1.30	38.2
Lo	.41	110	.62	29.6
Mean	.88	207	.84	34.0

	Plasma hgb	Platelet	Hematocrit
Hi	Increase=42.5mg/dl	Decrease=77%	Decrease=47%
Lo	Increase=−20.8mg/dl	Decrease=31%	Decrease=24%
M	Increase=13.5mg/dl	Decrease=48.6%	Decrease=33%

Discussion

It is obvious from the BGA data that early in this experience (the FDA trials), blood gases were not precisely controlled. However, once experience was gained and the appropriate equations developed describing the relationship between body size, FiO_2, and ventilation rate, good results were highly reproducible. This precision of control may well result in reduced dependence on frequent BGA.

The drop in platelet count exceeding the dilutional effect as shown by the hematocrit and hemoglobin data may be explained by two factors. During the FDA trials, two patients received packed red cells in the prime which alters the red cell dilutional rate. Secondly, it has been demonstrated that HES usage in the prime of the CPB circuit is attended by a drop in platelet count that is greater that the dilutional effect alone.[5,6]

The ease of set up, priming and operation make the M-2000 as convenient to use as bubble oxygenators. The safety and gentle blood handling characteristics documented during the FDA trials combined with the precise control of respiratory functions in the M-2000 make it a most acceptable addition to the growing family of membrane oxygenators.

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