
Pre-Clinical Evaluation of the Interpulse™ Membrane Oxygenator

Ronald J. Massimino, B.S., C.C.P., Karl E. Karlson, M.D., Ph.D., John Martin, C.C.P., Jeffrey D. Gough, B.A., C.C.P., Gary T. Stearns, C.C.P., Robert Dyer, B.S.

Evaluation conducted at:
Rhode Island Hospital
593 Eddy St.
Prov., R.I. 02902

Introduction

Attainment of a "state of the art" oxygenation system is the product of continual scrutiny and evaluation. In doing so, the perfusionist must constantly deal with the pros and cons of membrane vs. bubbler, and membrane vs. membrane.^{3,6,7}

The membrane vs. bubbler contention deals primarily with the manner in which the mechanics of respiratory exchange occur. Both accomplish the task of oxygenation; however, membranes lend themselves to a more physiologic treatment of cellular and plasma components without incurring the expense of microemboli generation.^{1,4,5,11} Also of consideration is the simplicity of the bubbler system in set-up and operation.

The membrane vs. membrane contention deals specifically with the more subtle distinctions between system designs. Due to the physical differences in membrane configuration, specific amounts and types of membrane material are required for optimum transfer.^{6,10} The ideal system then should consist of minimal membrane surface area capable of yielding maximum transfer.

Each membrane system varies in complexity due to

intrinsic design. In terms of set-up, operation, and potential cellular damage, a single pump system would be preferable to a dual pump system.⁹ However, high pressure gradients associated with single pump systems potentiate a higher risk of membrane rupture and/or maldistribution of flow.¹⁰ An integral heat exchanger which obviates the need for additional set-up time and the need for additional tubing and connectors also seems to be advantageous.

A perfusion system has been designed which incorporates the beneficial characteristics of both membrane and bubbler. The Interpulse*™ membrane oxygenator is composed of eight stacked membrane covered support plates forming seven blood channels (Fig. 1) The membrane material (Tetrafluoroethylene) is micro-porous with a mean pore size of 0.3 microns. The blood inlet and outlet manifolds are located on each end of the oxygenator. Five openings on each exterior plate provide access for oxygenator ventilation.

An integral heat exchanger is positioned on the venous side of the oxygenator. The heat exchanger sub-assembly is composed of forty epoxy-coated, thin-walled aluminum tubes running transversely across the blood path. Venous blood passes across the tubes perpendicular to the water flow.

The theory of operation of the oxygenator is based on:

- 1) Furrowed membrane channel wall geometry.
- 2) Pulsatile blood flow.

Please direct communications to: Ronald J. Massimino, 106 Moorefield St., Prov., R.I. 02909.

Article presented at AmSect's 19th Int'l. Conference, March 1981, San Francisco, CA, accepted September 13, 1981.

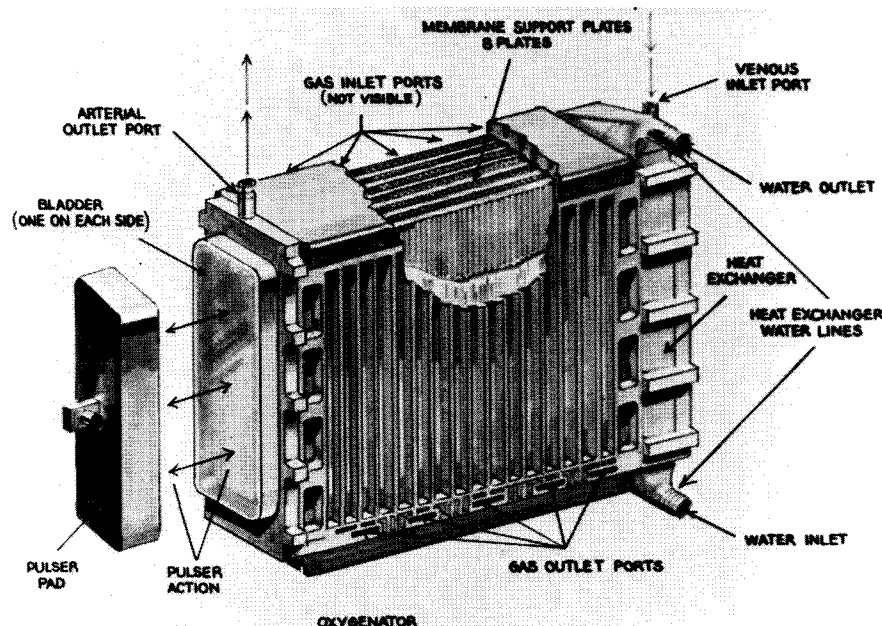


FIGURE 1. Interpulse™ Membrane Oxygenator.

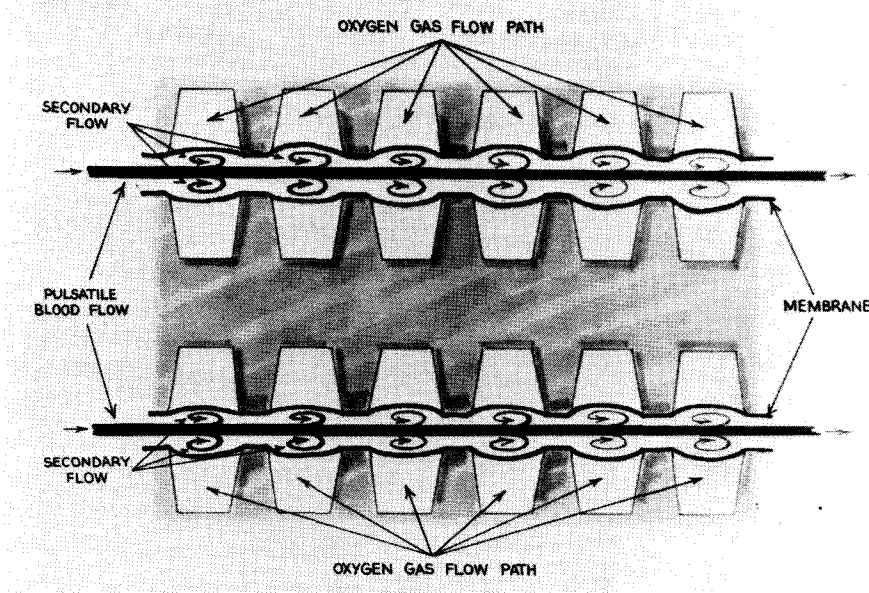


FIGURE 2. Furrowed membrane channel wall geometry.

Each support plate is grooved perpendicularly to the direction of blood flow (Fig. 2). The membrane is supported over these grooves in such a manner as to form a series of longitudinal furrows or sinuses. Gas flows in the space between the membrane and the support plate and blood flows between adjacent membranes. Flexible diaphragms on either end of the oxygenator allow a pulse to be transmitted to the blood spaces. The furrowed wall geometry and the pulsation of the diaphragm create secondary flows or vortices in

the channel furrows. The secondary flows serve to mix the blood, washing the membrane surface with oxygen deficient blood and displacing oxygen-rich blood back to the mainstream of flow, thus enhancing gas transfer. This is accomplished mechanically by the Interpulse*™ pulser module, the action of which rapidly displaces the diaphragms on each end of the oxygenator

* Extracorporeal Medical Specialties Inc., King of Prussia, Pa.

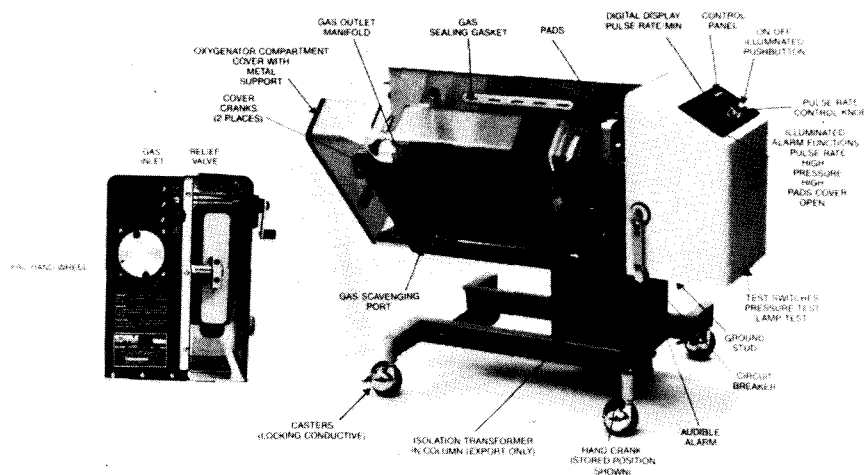


FIGURE 3. Pulser Module.

blood compartment in a reciprocating fashion. The entire unit consists of a stainless steel lined compartment for the oxygenator and an acrylic cover (Fig. 3). Metal covers enclose the main pulser frame which is mounted on locking casters for mobility.

Methods and Materials

This series of perfusions evaluated the efficacy of the Interpulse*TM membrane oxygenator during cardiopulmonary bypass in calves. Each calf was subjected to clinical and hematologic evaluation prior to, during, and immediately post bypass. A microemboli detection system** monitored contaminants down to 40 microns alternately upstream and downstream from the oxygenator. For all experimental conditions, counts were monitored for 4 to 5 minutes alternating upstream and downstream.

Thirteen Holstein calves weighing between 100–150 Kg. were used. The calves were acclimated to the facilities for at least 18 hrs. and were certified healthy by a licensed veterinarian. The calves were anesthetized using Fluothane and Pentobarbital and then intubated. Esophageal and rectal temperatures, EKG, and arterial and venous pressures were monitored. A peripheral ear artery was used to monitor arterial pressure while central venous pressure was monitored via the external jugular vein. Right thoracotomies were performed. All animals were given an initial dose of 250 I.U./Kg. of beef lung heparin. A dose-response curve was then

calculated to determine optimum heparinization.² A Hemochron*** activated clotting time of 600 seconds was maintained. Two 38F cannulae**** were then placed in the superior and inferior vena cavae for venous drainage. A 22 French cannula**** was placed in the carotid artery for return.

Each perfusion circuit consisted of a Bentley Q-220⁺ cardiotomy reservoir, an Intersept⁺⁺ cardiotomy filter, a Sci-Med 1300⁺⁺⁺ venous reservoir bag, an Interpulse⁺⁺⁺⁺TM oxygenator, and appropriate tubing and connectors (Fig. 4). Initial gas flow composition was 100% oxygen. Initial gas flow rate was 15 L/Min. Venous oxygen saturation and carbon dioxide tension were maintained as closely as possible to 65% and 45 mmHg., respectively. Arterial oxygen tension was controlled by pulser rate and arterial carbon dioxide tension was controlled by oxygenator ventilating gas flow rate.

The circuit requiring 2500 cc was primed with a combination of cellular and non-cellular components to maintain the hemoglobin as closely as possible to 12 Gm.%. Non-cellular components included Plasmalyte 148, Sodium Bicarbonate, beef lung heparin, and Calcium Chloride. No platelets were used to prime the circuit.

A three-stage process was incorporated to prime and

* Extracorporeal Medical Specialties Inc., King of Prussia, Pa.

** Micropure Inc., Greenville, Rhode Island

*** International Technidyne Corp., Metuchen, N.J.

**** C.R. Bard Inc., Billerica, Ma.

+ Bentley Laboratories Inc., Irvine, Ca.

++ Extracorporeal Medical Specialties Inc., King of Prussia, Pa.

+++ Sci-Med Life Systems Inc., Minn., Mn.

++++ Extracorporeal Medical Specialties Inc., King of Prussia, Pa.

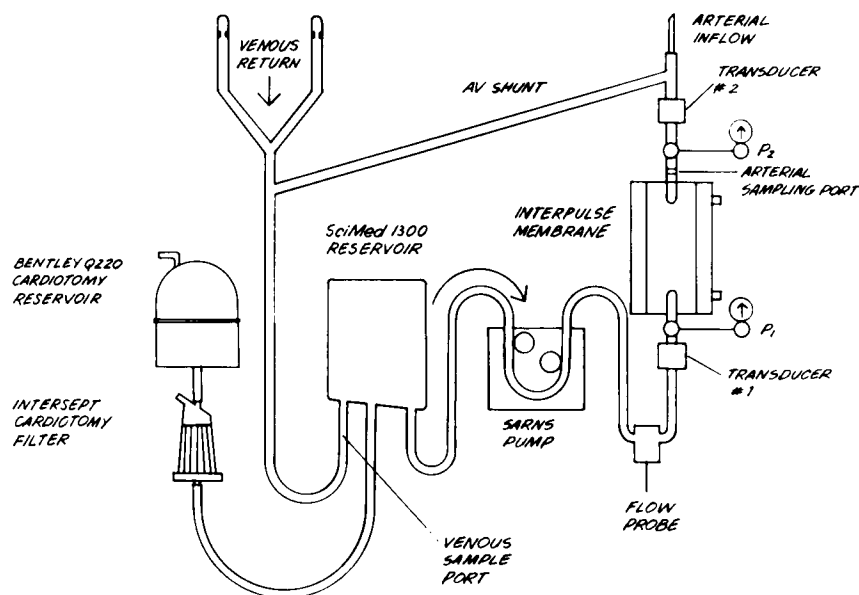


FIGURE 4. Perfusion circuit.

debubble the system. The first stage consisted of gravity filling the cardiotomy filter, then allowing the reservoir bag to fill by purging the displaced air from the top of the bag. The second stage included the gravity filling of the oxygenator and circuit tubing. A tube clamp was placed between the reservoir bag and the venous sampling port to which a purge line was connected. The other end of the purge line was connected to the cardiotomy reservoir. This enabled the displaced air in the circuit to be vented to the cardiotomy reservoir and not the reservoir bag.

Debubbling of the oxygenator with the pulser was the third stage in the priming technique. This was accomplished by establishing a pressure of approximately 100 mmHg. on the outlet side of the oxygenator. The pulser rate was slowly raised to 250 pulses per minute while maintaining a recirculation rate of about 6 L/Min. Any remaining air was removed via the stopcock on the reservoir bag. The entire priming process took no longer than 5 minutes.

Arterial and venous ph, pO_2 , pCO_2 , $O_2Sat.$, Hgb., and Total Bicarbonate were recorded every 30 minutes. Platelet number and plasma free hemoglobin were sampled prior to perfusion, at 3 hours of perfusion, and at the end of perfusion. Upon completion of bypass, protamine sulfate was administered to restore the an-

TABLE I
Acid-Base and Perfusion Data—13 Calf Perfusions

	Arterial		Venous	
	Mean	Std. Dev.	Mean	Std. Dev.
Ph	7.44 ± .07		7.40 ± .06	
PO_2 (mmHg)	122.4 ± 75.8		PO_2 (mmHg) 37.0 ± 7.6	
PCO_2 (mmHg)	30.8 ± 7.21		PCO_2 (mmHg) 35.2 ± 10.5	
O_2SAT (%)	94.1 ± 6.9		O_2SAT (%) 61.9 ± 11.7	
O_2Trans (ml/min)	229.9 ± 68.5			
Blood Flow Rate (L/min)	5.1 ± .5			
Pulser Rate (Pulse/min)	235 ± 26.0			
Inlet Pressure (mmHg)	286 ± 45.0			
Outlet Pressure (mmHg)	257 ± 44.0			
Delta Pressure (mmHg)	25.7 ± 9.2			
O_2Flow (L/min)	9.2 ± 4.0			
HCT (%)	31.7 ± 4.0			

TABLE II
Hematologic Evaluation—13 Calf Perfusions

	Pre Perfusion		3 hrs. Perfusion		End Perfusion	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Platelets (mm ³)	860 ± 383		653 ± 216		710 ± 353	
PL.Hgb (mg%)	39 ± 21		45 ± 23		39 ± 22	

imal to baseline clotting time. The chest incision was closed and anesthesia terminated. The animals were then sacrificed. Autopsies were not performed in this series.

Results

Acid-base and perfusion data for 13 calf perfusions at 36°C. or higher are illustrated in Table I. Blood-gas samples were drawn every 20–30 minutes and the results averaged to produce the figures shown in Table I (determined by nomogram). Bypass duration averaged 6 hours, with blood flow rates averaging 5.1 L/Min. Mean arterial pO₂ was 122.4 mmHg and arterial oxygen saturation was 94.1% or greater. Venous oxygen saturation averaged 61.9%. The average oxygen transfer for all trials was 229.9 ml/min. The average pulser rate was 235 PPM. The inlet oxygenator pressure was 286 mmHg and the outlet pressure was 257 mmHg, resulting in a mean pressure gradient of 29 mmHg.

Hematologic evaluation reflected a decrease in platelet numbers over a 6 hr. period from 860,000 to 710,000. Plasma free hemoglobin values exhibited no change. (Table 2)

Microemboli evaluation revealed no contaminants, either air or solid, from the oxygenator.

Discussion

Normal acid-base parameters were maintained during cardiopulmonary bypass without difficulty. Oxygen transfer was achieved with pulser rates slightly less than the suggested maximum (250PPM). This appears to indicate that this device will perform well during clinical conditions of hypothermia and hemodilution. The system can be set up and primed in less than 10 minutes. Volume requirements (approximately 2500 ml) are comparable to our present membrane system.

In a simulated oxygenator failure, changing and priming of this device was accomplished in 46 seconds.

References

1. Abts, L. R., Beyer R. T., Galletti, P. M. et al: Computerized Discrimination of Microemboli in Extracorporeal Circuits. *Am Jour Surg.*, 135, 1978.
2. Bull, B. S., Huse, W. M., et al: Heparin Therapy During Extracorporeal Circulation, *Journal of Thoracic and Cardiovascular Surgery*, 69, 5, 1975.
3. Hicks: Membrane vs. Bubble Oxygenators: *Arch. Surg.*, 1979.
4. Hill, D. G., LeLanerolle, P., Kosek, J. C., et al: The Pulmonary Pathophysiology of Membrane and Bubble Oxygenators, *Transactions*, 21, *ASAIO*, 1975.
5. Liddecoiel J. E., Bekassy, S. M., Beall, A. C. et al: Membrane vs. Bubble Oxygenators: Clinical Comparison. *Ann. Surg.*, 181, 1975.
6. Page, P.: Clinical Evaluation of a New Microporous Teflon Membrane Oxygenator. *JSECT*, 6, (4), 1974.
7. Pierce: The Membrane vs. Bubble Oxygenator Controversy. *Ann. Thorac. Surg.*, 29, (6), 1980.
8. Saxena, N. C., Hillyer, P., Edmunds, L.: Use of the Spiral Coil Membrane Oxygenator for Open Heart Surgery in Infants and Children. *J. Card. Surg.*, 18, 1977.
9. Trudell, L. A.: The Future of Membrane Oxygenators, 10 (3), *JSECT*, 1978.
10. Wheaton, R: Short Term Cardiopulmonary Bypass with the Sci-Med Kolobow Membrane Lung, 10, (3), *JSECT*, 1978.
11. Wright, J. J., Fisk, G. C., Torda, T. A. et al: Some Advantages of the Membrane Oxygenator for Open Heart Surgery. *Jour. Thorac. Card. Surg.*, 69, 1975.