
A Technique for the Effective Removal of Air from a Hollow Fiber Membrane Oxygenator Circuit

Richard Berryessa, Charles M. Tyndal, Jr., and Susan Tornabene

PSICOR Inc., Brighton, MI
University of Colorado Health Sciences Center, Denver, CO
and
The Childrens Hospital, Denver, CO

Abstract

This paper describes some of the ways unwanted air can be introduced into a cardiopulmonary bypass circuit and a technique which has been shown to significantly decrease the resultant bubble counts. In this study air was introduced into a circuit (Hct. 20%) containing a Hollow Fiber Membrane Oxygenator (HFMO). Conventional techniques of recirculation (3 L/min.) and vigorous agitation/percussion were compared to recirculation with vacuum (gas phase of HFMO) for efficiency in reducing bubble counts measured after three minutes by a microbubble counter.

Conventional methods were ineffective after three minutes while vacuum for 3 minutes significantly ($p = .001$) reduced bubble counts (bubbles > 100 microns).

The microporous membrane allows efficient air removal with vacuum while recirculation/percussion did little to remove air which, in a blood perfusate, was not visible to the naked eye.

The application of vacuum not only increases safety but convenience when used in the priming and debubbling of a circuit in routine and emergency case.

Introduction

There are a number of ways that air can enter a cardiopulmonary bypass circuit. Some of these are probably not of any consequence. Air in the venous return of a bubble oxygenator is dealt with easily. Air in the venous line of a membrane oxygenator circuit can be more troublesome.¹ Air in the arterial line is a problem in any kind of circuit. To remove arterial line

air in a bubble oxygenator circuit is perhaps not as difficult as in a membrane circuit. We have had air in the arterial line of a Hollow Fiber Membrane Oxygenator (HFMO) circuit and we were concerned about how we could remove it from the circuit in the most efficient and timely way. We have had a pinhole in the tubing on the negative side of the pump. This allowed air to be drawn into the crystalloid priming solution at a very slow rate during recirculation and debubbling and was visible only when the pump was stopped to hand the lines up to the operative field and small bubbles rose slowly out of the fiber bundle. We have had students and staff draw five or ten cc's of priming solution from the circuit to fill pressure lines or mix drugs only to draw air across the microporous membrane because they forgot that this can happen under certain circumstances. We have had residents connect the arterial line to the aortic cannula and without removing the clamp from the cannula, evacuate air in the line with a syringe through a stopcock. This draws air across the membrane which bubbles mysteriously up the arterial line as if out of nowhere. We have had lines blow off a membrane oxygenator when a 1/4" arterial line became kinked at the table. We have had PVC tubing split in the roller head and need replacement. We have had busy perfusionists, during recirculation and prior to bypass, forget a clamp on the cardiectomy return line, fill the cardiectomy reservoir from their filter purge or VRB air evacuation lines and empty the VRB.

From our previous experiences with a micro-bubble counter we knew how difficult it is to remove bubbles from a circuit simply by recirculating. We also knew that it is impossible to see even large bubbles in a circuit in which there is any blood. The purpose of this study was to see if there is a difference in micro-bubble counts when air is allowed to enter a HFMO circuit after three minutes of recirculation with or without vacuum applied to the gas phase of the HFMO.

Direct communications to: Richard Berryessa, C.C.P., PSICOR Inc., 810 East Grand River, Brighton, MI 48116

Materials and Methods

A HFMO circuit was constructed using a 1000 c.c. Terumo^a VRB, a Bentley^b CM50 HFMO and twelve feet of 3/8" I.D. PVC tubing. A TM-8^c micro-bubble activity monitor set at 100 microns was attached to the tubing with an ultrasonic gell interface. A luer-lok connector with a stopcock was placed in the line between the outlet of the VRB and the inlet of the oxygenator. The circuit was primed with normal saline and outdated (microfiltred) human blood to a Hct. of 20%. With the pump flow at three liters per minute three cc's of air was slowly (over 2 seconds) injected into the line and the timer started on the bubble counter. One group of samples (Group 1, n=6) was taken with nothing attached to either gas port. Another group of samples (Group 2, n=6) was taken with unregulated wall vacuum applied to one gas port of the HFMO and a piece of tubing attached to the other gas port and clamped. The sample groups were alternated. After the injection of air the oxygenator was vigorously shaken and beaten with a tubing clamp in the usual and traditional fashion for three minutes. At the end of three minutes the oxygenator was left untouched and micro-bubbles counted for one minute. At the end of one minute the circuit was "vacuumed" until bubble free (bubbles>100 mic.) for two minutes and the next test was conducted. All data were subjected to statistical analysis using the Statworks^{™d} statistical package and a 512K Macintosh^e computer. Unpaired Students T test was used to compare the difference between bubble counts in Group 1 and Group 2. Values are reported as mean $\pm$ standard deviation.

Results

Group 1 bubble counts (bubbles>100 microns) were 312.83 ± 162.65 while Group 2 bubble counts were 21.00 ± 17.84 . Group 2 (vacuum) bubble counts were significantly lower than Group 1 (no vacuum) counts ($p=0.001$).

Discussion

There is controversy about the clinical significance of bubbles given to patients by perfusionists. Primitive oxygenating devices, which served us well until this generation of membranes came along and which cer-

tainly are of historical interest, are finally falling into well deserved obscurity. These devices made bubbles and often, but not often enough, made the bubbles go away. There is literature to suggest² that even bubbles in the 16–20 micron range are obstructive to blood flow and that there is permanent damage caused by bubbles that are too small to see.³ We chose to measure bubbles larger than 100 microns because we think that there can be little doubt (in the mind of someone who has read the literature) that 100 micron bubbles cause damage^{3,4,5} that is significant.

In all our membrane oxygenator circuits we use an anesthetic gas scavenging system connected to vacuum. This is attached to the gas outlet port of HFMO. There is a "Y" connector, with an open piece of tubing attached, in the line to prevent the possibility of obstructing the gas outlet port and building up excessive positive pressure in the gas phase of the lung. If we were to get air in the circuit during a case we would recirculate (either through the recirculation line or the a-v loop, as the conditions warranted) with the gas inlet line turned off and the tubing on the safety limb of the gas scavenging system clamped to create negative pressure in the gas compartment of the HFMO. We have found that by increasing the pressure head in the blood phase of the lung (further increasing the pressure differential between blood and gas compartments) that debubbling time is decreased (unpublished data). Increasing flow through the recirculation line also improves debubbling times.

"Vacuuming" a microporous membrane oxygenator can be beneficial when there is air in the circuit. Provision for the possible need to vacuum can be made without any special effort in most cases. The need to remove as much air as possible from a circuit that has been compromised is obvious.

References

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a Terumo Corporation, Piscataway, NJ, 08854

b American Bentley, Irvine, CA, 17502

c Technique Laboratories, Hants, England

d Cricket Software, Philadelphia, PA 19104

e Apple Computer Inc., Cupertino, CA 95014

Questions from the Audience

Question—Robert Smith: Some of the current generation of hollow fiber membranes have their gas compartment vented to avoid positive pressure. Have you looked into how negative pressure might be applied to these?

Answer: Guess you're talking about the Maxima, for instance. The Maxima has three gas outlets on it. One is the standard one-quarter inch gas outlet port, the second visible gas outlet slit on the underside of the oxygenating chamber and then a hidden gas outlet around the union between the heat exchanger and the oxygenator portion of the lung. We have thought about modifying ourselves by using bone wax around the bottom of that union, between the heat exchanger and the gas compartment—which works. And then put a little piece of tape over the outlet, which is then subsequently removed before going on the pump. The only concern I have about that is that you're then altering a manufacturer's product and I'm not sure about the liability associated with doing that. The next best thing is to get the manufacturer, in this case J & J, in their next generation of oxygenator, to come to believe in the concept of being able to vacuum the circuit and allow for that to be done very easily. I think that may in fact be the case with the Maxima II, which will be out some time next year. If you were to get into a problem in the middle of a case and somehow get air in your circuit, and you wanted to get it out, you really don't have time to go find the bone wax, and wax that thing, and get the tape, and put it over the system. It's nice to be able to use this technique in a very expeditious and easy way.

Question—Richard Karmer: You are talking about using vacuum when you are priming the lines. Did you also just mention that you use vacuum applied to the system if you saw air during the case?

Answer: If you found the air in the arterial line during the case, you would put vacuum on, clamp the gas outlet port. We use vacuum continuously, but it's a vented system, and it's used to scavenge volatile anesthetic agents added through the gas phase of the circuit. But that is not a system that is a closed negative pressure system.

Question—Richard Kramer: Do you know approximately how much vacuum is continually being applied through the gas phase of the membrane? In the system you are referring to? I'm presuming that if you are open to the atmosphere, is it a partial opening, in the sense that you are creating a venturi through the atmosphere? Are you able to keep a low level of vacuum on the gas phase continuously?

Answer: I'm not sure what the pressure is, but I'm sure it's very low. I doubt that it's a significant negative pressure because of the open equally sized outlet on the gas scavenging system. And it's pretty standard. I think in some cases we use a one-half inch opening, and in some cases, a one-quarter inch. But with the outlet clamped, the negative pressure in the gas phase approaches somewhere between 100 and 200 millimeters of mercury.

Question—Mark Kurusz: Tape on the outlet. It's dangerous. There have been patient fatalities. I would really caution everyone in the audience. Your technique of raising the delta P through the device—I assume you also applied vacuum at the same time. Is that right?

Answer: Right. Vacuum on the gas phase. Recirculation through the blood component of the system, and partially clamping the arterial line to drive the pressure up to about 200.

Question—Mark Kurusk: The question is: Do you have any indication, in the momentary clamping of the line, whether in fact your just compressing the bubbles, and as soon as you release the clamp, do they resume their normal shape?

Answer: We did not just temporarily clamp the line. We clamped it for about three minutes, took the clamp off, and to tell you the truth, I'm not sure we looked at the bubble counts, after the clamp was off, to see if they went back up.