Membrane Versus Bubbler

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Membranes were first conceived in the early 1950's. Development of this type of device seemed the logical approach because of the obvious disadvantage of the bubble oxygenator, namely, the direct contact of gaseous oxygen and blood precipitating considerable blood trauma.

Membrane technology has literally raised the method of respiratory exchange from an unphysiologic, mechanical mixing of oxygen and blood to a gentle, molecular exchange of gases across a variety of membrane materials. Our institution's experience with membrane oxygenation spans 12 years. The conclusion that we derived from the accumulation of clinical and investigational data is that membranes lend themselves to a more physiologic treatment of cellular and plasma components without incurring the additional insult of microemboli generation.

Time does not permit me to elucidate all the studies that have been reported by other investigators. However, I would like to highlight a few that have addressed some of the more controversial issues. In 1975 Solis studied particulate microemboli and in vitro platelet aggregation in patients during cardiac operations with bubblers and membranes using Coulter counter and ultrasound. His results documented a significant increase in the volume of particulate and air emboli in the bubbler over the membrane.

In our experience with bubblers, we have never been able to attain an emboli free circuit. In fact, our most reliable source of emboli generation for evaluation of arterial filter efficiencies is the bubble oxygenator. Carlson also counted fewer gas and particulate emboli in the arterial line of the membrane compared to that of similar patients with the bubble oxygenator. (1,500 counts/min. versus 18,000 counts/min.) Sonar counts correlated well with mental sequelae measured by Bender-Gestalt visual motor tests. A comparison of pre- and post-operative scores revealed that 9% of patients with membrane and 40% of patients with bubble oxygenators had deterioration of -10 of pre-operative scores.

It has been reported by Stoney that most accidents that occur during perfusion are related to some type of inadvertent air embolism. By survey one in every 1,000 patients suffer injury or death as a result. Closed membrane systems, specifically the use of collapsible reservoir bags, offer much better protection to the patient and possibly produce a real decrease in morbidity and mortality. Sade in his work with membranes states "The membrane oxygenator offers an additional degree of protection from the possibility of massive air embolism." Better control of blood volume is also obtained by this method, which has proven to be especially helpful upon initiation and termination of bypass.

In the literature there is a tremendous amount of evidence that membranes produce less trauma to the formed elements and proteins of blood, in-
duce little or no air and solid particles, and are responsible for less organ damage than bubblers. Pranger in his study with dogs found a clear distinction between bubbler and membrane groups when utilizing $pO_2$ histograms. In the bubbler group, impaired $pO_2$ histograms were observed which coincided with a high systemic vascular resistance, low cardiac output, and decreased platelet numbers. In comparison, the membrane group had normal histograms, normal systemic vascular resistance values, normal cardiac output, and better maintained platelet numbers.

Peterson, in his work with Indium-111 labeled platelets data, indicated that "Membrane oxygenators maintain a higher circulating platelet count both intra-operatively and post-operatively and result in less platelet destruction than bubble oxygenators following 1 hour of cardiopulmonary bypass in dogs. This work sheds some light on the potential short term benefits of membrane use.

Mortensen studied plasma hemoglobin in bubbler and membrane. His results showed that curves plotting plasma hemoglobin concentration against time for the four oxygenators tested (2 bubblers and 2 membranes) were significantly different. One circuit containing a membrane oxygenator produced no more plasma hemoglobin after six hours of recirculation than did control circuits with no oxygenator. The second membrane oxygenator was likewise only mildly hemolytic to blood, producing a plasma hemoglobin concentration of 79.5 mg% after six hours of recirculation. On the other hand, both bubble oxygenators produced much higher plasma hemoglobin concentrations than did either of the membrane oxygenators (379 mg% and 441 mg% respectively). These data were all statistically significant.

Shelton studied various hematological parameters in his comparative study of membrane and bubbler. In the bubbler group, there was a 47.4% decrease in platelet number, thoracotomy drainage averaged 736 ml., and blood was required for 77.5% of the patients. In the membrane group there was only a 25% decrease in platelet number, thoracotomy drainage was less (mean of 488 ml) and blood was only required for 48.5% of these patients. Liddicoat analyzed hemodynamic parameters in 91 patients (46 with membrane and 45 with bubbler) according to the duration of cardiopulmonary bypass. Fluid and blood balance, as well as hematologic and blood gas studies, were used for comparing the two oxygenators.

These results showed that the hemodynamic parameters were better, and the arterial blood gases were more physiologic with the membrane oxygenator. The post-operative blood loss was significantly less when using the membrane and the other measurements documented the stability of this device. Consequently their institution is using the membrane for routine cardiopulmonary bypass.

Mechanical control of $pO_2$ with bubblers is difficult and unpredictable, especially during the rewarming phase of bypass. Gas-to-blood flow ratios must be increased to eliminate carbon dioxide retained during the hypothermic phase. As a result, elevated $pO_2$'s may be and are experienced. Membranes, on the other hand, afford the operator separate and accurate control of $pO_2$ and $pCO_2$ during all phases of perfusion. This is supported by Peters in his comparative study of the Interpulse membrane vs. the Harvey H-1000. He concluded that "Blood gas control was very remarkable with the membrane oxygenator during long perfusion. $pO_2$ and $pCO_2$ could be maintained at near physiologic levels. This could not be done with a bubble oxygenator."

Two secondary, unscientific objections to membrane systems are set-up time and operational complexity. In our experience, we find no difference. Until set-up time is entered as an official Olympic event, this objection has no significance. Secondly, the objection of increased complexity may have been valid 10 years ago. The more recent membrane devices, which closely mimic bubbler design, can hardly be called complicated to the qualified clinical perfusionist.

The greatest strength of membranes, of course, is their superiority for long term support. The level of trauma from a membrane oxygenator is clinically tolerable for many days while the safe perfusion period with the bubble oxygenator is measured literally in hours. For the occasional unpredictable patient who requires prolonged circulatory support, routine use of a membrane would circumvent this problem. One could even speculate that routine use of membranes could poten-
tially reduce the need for prolonged circulatory support.

It is a fact that a bubbler system is cheaper than a membrane system. However, is the cost of the system the only consideration? Heimbecker states "Because of greatly reduced blood usage, the total cost of a procedure with membrane oxygenation is much less." Morris in his comparisons found the average savings (total hospital cost) of $450 with the membrane system, justifies the additional cost. And finally, Peters concluded "The decrease in total blood products used per patient in the membrane group far covers the patient cost increase over bubble oxygenator."

In summary, the literature has documented the superiority of membrane over bubbler, and has also documented the lack of superiority of membrane over bubbler, but never has there been documentation of the superiority of a bubbler over a membrane. As perfusionists, we have a professional and ethical responsibility to provide our patients with the best possible technology available that is suited for all eventualities.

Based on the theoretical and clinically documented superiority of membrane oxygenation, it would appear that these devices are the obvious choice for routine circulatory support. In the words of Lee Iacocca "If you can find a better device, buy it."

References

The Case for Bubble Oxygenators

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The bubble versus membrane controversy has been around for years, with bubble oxygenators unjustifiably accused of being inferior to membrane oxygenators. Many of the proponents of membrane oxygenators have based the theoretical superiority of these devices on data that just isn't pertinent to perfusion or isn't really substantiated in the literature. The proponents of membrane oxygenation generally promote these devices on the basis that they reduce blood trauma by eliminating the blood gas interface found in bubble oxygenators and that membrane oxygenators are the "safest and most physiologic form of extracorporeal oxygenation." It has become axiomatic that a membrane oxygenator is theoretically superior to a bubble oxygenator. I will concede that mem-