

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? Heimbecker¹¹ states "Because of greatly reduced blood usage, the total cost of a procedure with membrane oxygenation is much less." Morris¹² in his comparisons found the average savings (total hospital cost) of \$450 with the membrane system, justifies the additional cost. And finally, Peters¹⁰ 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."

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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 oxy-

genation 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-

brane oxygenators (M.O.) are basically different—but certainly not superior to the bubble type of oxygenator.

Let's review some of the studies the membrane proponents have used to reach their conclusions of "membrane superiority." In his paper on "Denaturation of Plasma Proteins as a Cause of Morbidity and Death After Intracardiac Operations," published in 1961, Lee et al.¹ stated, "For more than twenty years the denaturation of protein molecules by contact with an interface between a gas phase such as air and a water phase such as blood has been recognized."

It was this early work of Lee's group that really spurred the further development of M.O.'s. Cited as references were articles by Bull and Neurath,² Neurath et al.,³ Anson,⁴ and Cheeseman and Davies,⁵ and others.^{6,7,8}

Lee et al. and many subsequent investigators refer to these papers as the theoretical basis of the blood gas interface causing blood trauma. Let's examine these reports to see how they apply to the problem of the extracorporeal oxygenation of blood. Bull and Neurath shook an egg albumin mixture in a glass bottle at 2 degrees centigrade. They found that protein denaturation occurred most rapidly at a 4.8 pH, but virtually no denaturation took place even after 12 hours at a 7.4 pH. Anson discussed denaturation in general, but not denaturation at a liquid gas interface. Cheeseman and Davies discussed the behavior of a protein at air-water interfaces, but state only that the rigidity of a protein molecule is reduced at such an interval. They further state that at physiologic pH and temperature: "It may be seen that the total internal cohesion remains high even when a protein molecule is spread at the air-water interface."

Although liberally referenced in the literature promoting membrane oxygenators only a few of these articles even remotely apply to the problem of extracorporeal circulation of blood. One cannot extrapolate from these reports that any significant denaturation occurs in a modern bubble oxygenator at physiologic gas tensions and temperatures.

A recent prospective randomized study by Sade et al.⁹ published in June 1980, from the Medical University of South Carolina, compared membrane and bubble oxygenators in pediatric patients, and found on their subset, of short bypass

cases that immunoglobulin G, total protein, and total albumin were significantly higher in the bubble oxygenator group than in the membrane group. They also reported no significant differences in the plasma protein measured in their subset with long bypass times. This group was not a casual user of membrane oxygenators but a long time proponent of membranes.

For years membrane proponents have told us that membrane oxygenators reduce destruction and dysfunction of platelets, reduce hemolysis, and reduce post-operative bleeding when compared to bubble oxygenators. Recent studies by Sade,⁹ Edmunds,¹⁰ Trumbell,¹¹ and Tabak,¹² do not substantiate or refute the significant differences claimed by membrane proponents.

In two recent studies comparing membrane and bubble oxygenators and their effects on platelets, Edmunds¹⁰ at the University of Pennsylvania and Trumbell¹¹ at the University of Minnesota reported that platelet counts corrected for hemodilution actually increase during and after cardiopulmonary bypass in both membrane and bubble oxygenators. They further report that the increase in relative platelet count was significant in the bubble oxygenator group and not significant in the membrane oxygenator group. Sade's⁹ study at the Medical University of South Carolina did not report any significant differences in platelet counts between membrane and bubble oxygenators.

However, if their data is corrected for hemodilution and subjected to analysis based on the percent change in platelet count over pre-bypass levels, a substantial percent decrease in corrected platelet count is seen for the membrane group at all points measured during and after bypass. These studies, all published within the last three years, contradict the membrane proponents theoretical argument for routine use of membrane oxygenators based on their ability to conserve platelets when compared to bubble oxygenators. In fact, they present to bubble oxygenator manufacturer some clinical evidence to argue for bubbler use based on platelet conservation, the same argument that membrane proponents have used for years.

Another frequently used argument for the routine use of membrane oxygenators is that membranes reduce post-operative bleeding. Again, recent studies by Edmunds,¹⁰ Sade,⁹ Hessel¹³ and others,^{14,15,16} have found no differences in post-

operative blood loss between the two types of oxygenators.

Membrane proponents claim their systems reduce hemolysis during cardiopulmonary bypass. Studies by Hessel,¹³ and others^{15,17,18} observed no differences in the degree of hemolysis, as indicated by plasma free hemoglobin levels, between membrane and bubble oxygenators. A recent study by Tabak et al.,¹² using sodium chromate tagged erythrocytes, reported no differences between membrane and bubble oxygenators as a cause of red cell injury. Although Sade⁹ reported statistically higher plasma hemoglobin in the bubble oxygenator group in their study, it was only at three of the six time intervals sampled. They go on to say "Although statistically significant, the differences were not large and probably have little clinical importance."

Failure by membrane proponents to prove their superiority over bubble oxygenators, based on the theoretical differences in how they handle plasma proteins and formed elements in the blood compared to the actual differences reported in the literature, have led to a new tactic for justifying their routine clinical use.

Membrane proponents have turned to pointing out the perceived safety aspects in the prevention of massive air embolism, the claims of better volume control during cardiopulmonary bypass, the cleanliness of the membrane oxygenator, and the simple and reproducible blood gas control of the membrane oxygenator.

I have been unable to find any claim by manufacturers of membrane oxygenators that their devices preclude the possibility of massive air embolus. Therefore, the same precautions must be taken by the perfusionist to prevent massive air embolus, as they are with the use of a bubble oxygenator. In fact, the oldest manufacturer of membrane oxygenators recently introduced its newest device, which has all the inherent risks of massive air embolism of a bubble oxygenator in that it employs pumping directly from a hardshell arterial reservoir. The manufacturer's answer to preventing air embolism is to employ a level detection device on the oxygenator to alarm and shut down to prevent the accidental pumping of air. Similar devices have been available for a number of years for use with bubble oxygenator systems. Yet nothing can replace the perfusionist's diligence in

preventing the emptying of the oxygenator's contents, either with a membrane or bubble oxygenator. A further concern with microporous membrane oxygenators is the accidental overpressurization of the gas side of the device and the introduction of air across the membrane to the blood side resulting in arterial air embolism.

Several studies on particulate emboli in the cardiopulmonary bypass circuit^{19,20} indicate that emboli are present in both membrane and bubble oxygenator circuits prior to bypass. The use of "pre-bypass filters" for removal of particulate emboli in bubble oxygenators should overcome the argument by membrane proponents that because "membrane oxygenators can be washed during the manufacturing process" they are cleaner than bubble devices. The use of arterial filtration during bypass further reduces both particulate and gaseous emboli and should be used with either type oxygenator.

Volume control on initiating bypass is a function of how slowly or rapidly the perfusionist initiates bypass. With a closed system the speed at which one can initiate bypass depends on the resistance in the venous line and compliance of the venous reservoir. By slowly releasing the venous clamp with a bubble oxygenator as the arterial pump speed is increased the perfusionist can achieve a smooth initiation of bypass with excellent volume control. During bypass, volume control is similar with either a bubble or a membrane oxygenator, in that you can only pump to the patient as much as you get back.

Membrane proponents would propose that we use membrane oxygenators because of their simple and reproducible blood gas control. With familiarity of the operating characteristics of different bubble oxygenators, one can maintain physiological gas tensions quite well.

Finally, there is the significant cost difference between the devices. If the 85% of the perfusionists using bubble oxygenators began using membranes overnight, it would increase hospital costs, at the present cost differences between bubble and membrane oxygenators, by over \$20,000,000 per year.

In the face of diagnostic related group (DRG) reimbursement now being implemented by Medicare, and other cost containing measures being taken by the private third party providers such as

Blue Cross, it will become increasingly difficult for membrane proponents to justify the increased cost for the routine use of membrane oxygenators based on their alleged theoretical "superiority."

In conclusion, since the first commercially available disposable bubble oxygenator became available over 18 years ago, many hundreds of thousands of surgical procedures employing cardiopulmonary bypass have been safely and economically performed, with very low mortality and morbidity, with the use of bubble devices.

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