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# Clinical Evaluation of Three Ultrafiltration Devices

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## Abstract

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**(J. Extra-Corpor. Technol. 19[3] p. 281–286 Fall 1987, 9 ref.) Three currently available ultrafiltration devices were evaluated with regard to rate of ultrafiltration, hemolysis and ease of use within the clinical setting. The Amicon Diafilter 30 Hemofilter, Minntech Corp. Hemocor Hemoconcentrator and Sarns Hemoconcentrator were tested in a total of 27 myocardial revascularization cases. While maintaining a constant flow through the ultrafiltration device, temperature, ultrafiltrate flow, hematocrit, plasma hemoglobin and transmembrane pressure were measured at the beginning and end of ultrafiltration and at ten minute intervals during ultrafiltration. The Amicon Diafilter exhibited an average ultrafiltration rate of .27 +/- .09 ml/min/mmHg while the Hemocor and Sarns Hemoconcentrators yielded rates of .33 +/- .10 and .55 +/- .09, respectively. The Sarns and Hemocor units showed a 39% and 26% increase respectively in plasma hemoglobin above the corresponding percent increase in hematocrit, indicating some degree of hemolysis. The Amicon unit showed a 43% and 92% increase in plasma hemoglobin in 2 separate trials. There was no measurable blood or protein in the ultrafiltrate of any of the units tested except for the Amicon, which showed trace to 1+ amounts of nonhemolyzed blood in 3 of 7 trials. The Sarns unit primed the most expediently, followed by the Hemocor and Amicon, respectively.**

## Introduction

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Hemodilution is commonly used as an adjunct to adult cardiopulmonary bypass (CPB) procedures. When used in conjunction with hypothermia, moderate

hemodilution counteracts the increase in viscosity caused by lower blood temperatures, helping maintain perfusion of the microcirculation.<sup>1,2</sup> The metabolic needs of the tissues decrease with temperature so that adequate oxygen delivery is possible at lower temperatures with moderate hemodilution. Hemodilution also causes a decrease in the plasma protein concentration. Depending on the oncotic properties of the diluting fluid, this may lead to third spacing of fluid into the extravascular space.<sup>3</sup> During the rewarming stage of CPB, the oxygen demand of the tissues increases, requiring a concomitant increase in oxygen delivery. Hemoconcentrators may be employed during this rewarming stage to increase the oxygen-carrying capacity of the blood (by increasing the hematocrit), minimizing the need for homologous bank blood. Use of a hemoconcentrator offers the added advantage of removing only plasma water, effectively concentrating plasma proteins and increasing the colloid osmotic pressure (COP), thereby encouraging the return of extravascular fluid into the intravascular circulation.<sup>3</sup>

There are several ultrafiltration devices (UFD) currently on the market. It is the purpose of this paper to evaluate 3 of these UFDs which, at our institution, are available at comparable costs.

## Materials and Methods

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The study encompassed a total of 27 clinical trials in patients undergoing cardiac revascularization. The Diafilter 30 Hemofilter<sup>a</sup> was used in 7 cases (26%), the Hemocor HC 500<sup>b</sup> in 6 cases (22%) and the Sarns Hemoconcentrator<sup>c</sup> in 14 cases (52%). Constraints on laboratory testing precluded further trials of the Diafilter and Hemocor units. The CPB circuit used in each case included the Shiley M2000 Oxygenator<sup>d</sup> and Fil-

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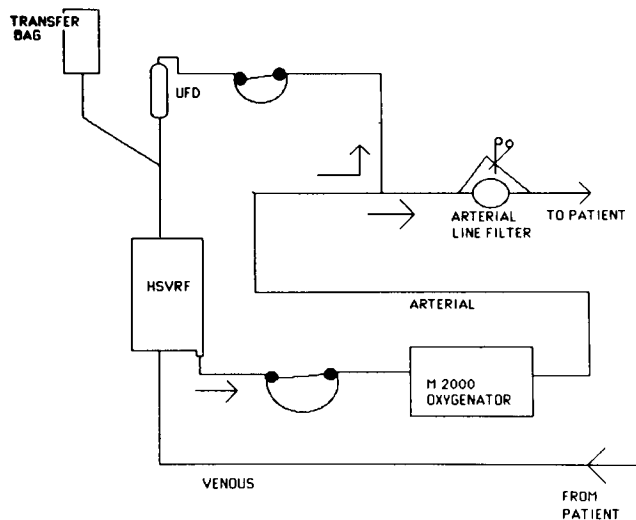
a Amicon Corporation, Danvers, MA 01923

b Minntech Corp., Minneapolis, MN 55441

c Sarns Inc./3M, Ann Arbor, MI 48106-1247

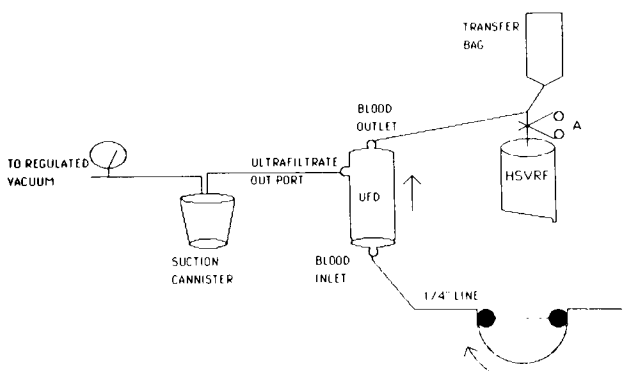
d Shiley Inc., Irvine, CA 92714

tered Hard Shell Reservoir (HSVRF)<sup>d</sup>, Pall arterial line filter (ALF)<sup>e</sup>, and a Sarns Integrated Cardioplegia Delivery System<sup>c</sup>. A calibrated roller pump was used to pump blood through the UFD from a 1/4 inch line off the arterial line, distal to the oxygenator and proximal to the ALF (Figure 1). The concentrated blood was returned to the HSVRF via a "Y" into the quick prime line. The circuit was initially primed with 5000 ccs crystalloid solution. Each UFD was primed according to manufacturer's specifications.



**Figure 1:** Cardiopulmonary Bypass Circuit Diagram.

The Diafilter and Hemocor units each required a minimal 2000 cc rinse. After clamps were placed on the ultrafiltrate outlet line and at position "A" (Figure 2), priming fluid was pumped through the UFD into the transfer bag. A total of 1000 ccs was collected and discarded. The ultrafiltrate outlet line was then opened



**Figure 2:** Diagram of circuit used for Diafilter and Hemocor ultrafiltration devices.

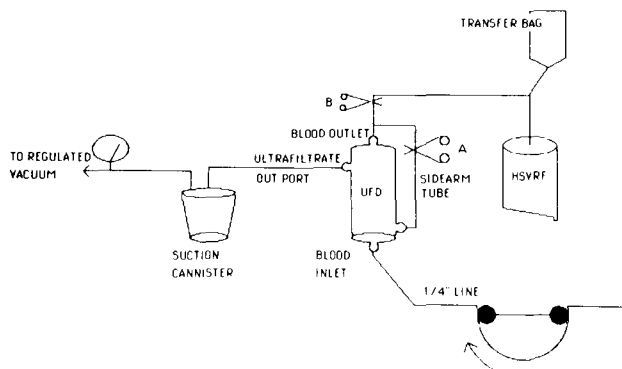
and clamp "A" was removed. Fluid was pumped through the UFD until 1000 ccs of ultrafiltrate was collected. The ultrafiltrate outlet line was clamped and the pump was turned off, completing the priming process.

The priming of the Sarns UFD was slightly different. With each unit, the manufacturer supplied a sterilized tubing pack. We adapted this to our circuit so that a sidearm tube was attached to the blood outlet port of the UFD (Figure 3). This sidearm tube bifurcated to a "Y", one end of which was attached to the lower ultrafiltration port of the UFD and the other end attached to the blood outlet of the UFD and "Y" into the quick prime line into the HSVRF. The sidearm tubing was clamped at position "B" (Figure 3) and priming fluid was pumped through the fibers of the UFD, exiting the blood outlet and entering the ultrafiltrate compartment via the lower ultrafiltration port. This fluid bathed the outside of the fibers, rising up in the ultrafiltrate compartment to exit the UFD through the upper ultrafiltrate outlet port into the collection cannister. After a minimum of 1500 cc flush was collected and discarded, the clamp was moved to position "A" and the pump was turned off, completing the priming process. Suction was not applied in priming any of the 27 UFDs tested.

After flushing the UFD, additional crystalloid was ultrafiltered off to achieve the optimal circuit volume as dictated by patient body surface area and hematocrit. Following this, 1000 ccs of 5% plasma protein fraction, 2 grams antibiotic and 12,000 units of heparin were added and recirculated throughout the circuit in accordance with our priming protocol.

Ultrafiltration was performed periodically throughout each pump run, depending on circuit volume, hematocrit and stage of the operation. During ultrafiltration, blood flow through each unit was maintained at 500 ml/min. When not hemoconcentrating, the ultrafiltrate outlet line was clamped and minimal blood flow was maintained through the UFD to prevent settling and stagnation of blood within the fibers. Pressure was measured immediately proximal to the blood inlet site of the UFD, while pressure at the blood outlet was assumed to be zero (since the HSVRF was vented to atmosphere). A regulated vacuum source was used to apply 200 mmHg suction to the ultrafiltration line in each unit tested. During ultrafiltration, blood temperature, ultrafiltrate flow, blood inlet pressure and hematocrit were measured at the beginning and end of ultrafiltration and at 10 minute intervals. Transmembrane pressure (TMP) was calculated as:  $TMP \text{ (mmHg)} = [\text{inlet pressure}/2] + 200$ . The ultrafiltration rate (ml/min/mmHg) was determined by dividing the ultrafiltrate flow (ml/min) by the TMP (mmHg). The Student's t-test was used to evaluate

<sup>e</sup> Model 3840, Pall Biomedical Products Corporation, Glen Cove, NY 11542



**Figure 3:** Diagram of circuit used for Sarns ultrafiltration device.

the difference in ultrafiltration rates of the three groups studied. After each trial, the ultrafiltrate was tested for gross amounts of blood and protein using Hemostix and Albustix<sup>f</sup>.

Free hemoglobin values were measured during three random trials in each of the three groups studied. These samples were drawn from a site immediately proximal to the blood inlet port of the UFD at the beginning and end of ultrafiltration. The net increase in free hemoglobin was determined by subtracting the initial or baseline value sampled at the beginning of ultrafiltration from the final value sampled at the end of the ultrafiltration period. The percent increase in free hemoglobin was compared to the percent increase in hematocrit, as has been reported in other studies.<sup>4,5</sup> Only data from trials in which no bank blood was added during ultrafiltration was used. Free hemoglobin values were converted to whole blood concentrations to avoid fluctuations in values incurred by plasma volume variations. The following formula was used:  $C_{WB} = C_p[(100 - Hct)/100]$  where  $C_{WB}$  and  $C_p$  is the free hemoglobin concentration in whole blood and plasma respectively (mg%), and Hct is hematocrit (vol%). The percent increase was determined for both the hematocrit and free hemoglobin values using the formula:  $\% \text{ increase} = [(C_{FIN} - C_{INT})/C_{INT}] \times 100$  where  $C_{INT}$  and  $C_{FIN}$  is the concentration measured at the beginning and end of the ultrafiltration period, respectively. The percent hemolysis was then determined as the difference between the percent increase in free hemoglobin as compared to the percent increase in hematocrit due to hemoconcentration.

## Results

Table 1 briefly compares the three UFDs studied with regard to certain manufacturer specifications. The

Hemocor and Diafilter units utilized similar priming techniques, requiring collection of one liter of ultrafiltrate and one liter of wash through the fibers. The Hemocor primed slightly faster than the Diafilter, due to the ultrafiltrate coming off more efficiently (i.e., prior to plasma addition). The Sarns unit primed the most expediently. By using the sidearm tubing, only one collection cannister was needed for waste, and essentially both the inside and outside of the fibers were rinsed simultaneously.

Table 2 represents a summary of the ultrafiltration data of the 27 trials, including the average blood temperature and hematocrit during ultrafiltration as well as the high and low ranges of each. The average TMP was 285 mmHg for the Diafilter, 253 mmHg for the Hemocor and 266 mmHg for the Sarns. The average ultrafiltrate flow was 72.79 ml/min for the Diafilter, 83.21 ml/min for the Hemocor and 145.18 ml/min for the Sarns. Normalizing the ultrafiltrate flow with TMP, the average ultrafiltration rate for the Diafilter was .27 ml/min/mmHg, and .33 and .55 ml/min/mmHg for the Hemocor and Sarns units, respectively. There was no statistically significant difference ( $p < .05$ ) between the ultrafiltration rates of the three groups of UFDs.

With regard to the composition of the ultrafiltrate itself, there was no protein detected in the ultrafiltrate from any of the UFDs tested. In 3 of the 7 Diafilter trials (43%), the ultrafiltrate showed trace to 1+ (from a scale of 0 to 4+) amounts of blood. In one of these trials, a blood leak from ruptured fibers was visually confirmed. Neither the Sarns nor the Hemocor UFDs had any measurable blood in the ultrafiltrate. In 2 of the 6 Hemocor trials (33%), it was noted that a significant number of the fibers failed to fill with blood. The cause for this was not apparent and it did not decrease the ultrafiltration rate in those units.

Figure 4 illustrates the net increase in plasma hemoglobin concentrations found in 9 trials. Each bar represents an individual trial. The duration period of ultrafiltration (TIME), the average TMP (TMP), the number of blood products added during the ultrafiltration period (# UNITS), and the total volume of ultrafiltrate removed (ULTRAF) are also included. Of the 3 Sarns UFDs rested, the net increase in plasma

**Table 1**  
**Comparison of Manufacturer's Specifications of Ultrafiltration Devices**

UFD	DIAFILTER 30	HEMOCOR HC 500	SARNS
MEMBRANE MATERIAL	POLYSULFONE	POLYSULFONE	POLYACRYLONITRILE
SURFACE AREA	.55 M <sup>2</sup>	.50 M <sup>2</sup>	.90 M <sup>2</sup>
MAX BLOOD FLOW	500 ML/MIN	500 ML/MIN	500 ML/MIN
MAX TMP	500 MM HG	500 MM HG	500 MM HG
PRIMING VOLUME	40 ML	39 ML	70 ML

<sup>f</sup> Ames Division, Miles Laboratories, Inc., Elkhart, IN 46515

**Table 2**  
**Summary of Ultrafiltration Data**

		DIAFILTER	HEMOCOR	SARNS
NUMBER OF TRIALS		7	6	14
TEMPERATURE	AVERAGE	32.76	32.72	33.64
	HIGH - LOW	24.0 - 37.8	24.0 - 37.0	22.4 - 37.3
HEMATOCRIT	AVERAGE	24.79	24.47	26.06
	HIGH - LOW	18.9 - 37.9	15.9 - 31.9	18.4 - 36.2
TMP (AVERAGE MM HG)		285	253	266
ULTRAFILTRATE FLOW (AVERAGE ML/MIN)		72.79	83.21	145.18
ULTRAFILTRATION RATE (AVERAGE ML/MIN/MM HG +/- SD)		.27 +/- .09	.33 +/- .10	.55 +/- .09

**Table 3**  
**Summary of Hemolysis Data**

	HEMATOCRIT		FREE HGB		% INCREASE		% HEMOLYSIS	
	INT	FIN	INT	FIN	HCT	FR HGB		
SARNS	22.0	30.8	18.6	33.2	40	79	39%	
DIAFILTER	21.9	30.5	25.0	57.7	39	131	92%	
HEMOCOR	19.9	24.5	42.0	69.8	23	66	43%	
	23.1	26.5	48.5	68.2	15	41	26%	

INT: INITIAL VALUES SAMPLED AT ONSET OF ULTRAFILTRATION  
FIN: FINAL VALUES SAMPLED AT END OF ULTRAFILTRATION  
HCT: HEMATOCRIT (VOL %)  
FR HGB: FREE HEMOGLOBIN (MG%, EXPRESSED IN WHOLE BLOOD CONCENTRATIONS)

hemoglobin ranged from 24.1 to 38.3 mg%, from 8.0 to 29.8 mg% for the Hemocor and from 20.0 to 51.0 mg% for the Diafilter.

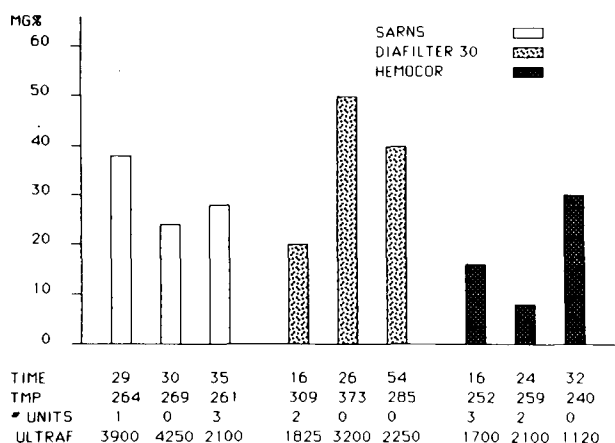
As shown in Figure 4, in 4 of the hemolysis trials, no blood products were added during ultrafiltration. The data from these trials were further evaluated to determine the percent increase in free hemoglobin (whole blood concentration) as compared to the percent increase in hematocrit. The Hemocor unit showed a 26% increase in free hemoglobin above that predicted from the concurrent increase in hematocrit. The Sarns showed a 39% increase and the Diafilter showed a 43% increase in one trial and a 92% increase in a second separate trial (Table 3). The increase in hemolysis seemed to be associated with higher TMPs. The Hemocor unit averaged a TMP of 240 mmHg, the Sarns unit 269 mmHg and the Diafilter 285 and 373 mmHg in the 43% and 92% trials, respectively.

## Discussion

The rate of ultrafiltration is affected by several variables including blood flow, hematocrit, temperature, TMP, protein concentration and associated COP. Since few of these variables remain constant within the clinical setting, clinical results must be interpreted from laboratory studies. Laboratory testing under controlled conditions shows the following results:

- Ultrafiltrate flow increases with increasing blood flow through the UFD at a given TMP, hematocrit and temperature.<sup>6,7</sup>
- Ultrafiltrate flow increases with increasing TMP at a given blood flow, temperature and hematocrit up to a maximum TMP, above which ultrafiltrate flow levels out.<sup>6,7,8</sup>
- At a given blood flow and hematocrit, ultrafiltrate flow decreases with decreasing temperatures.<sup>6,7,8</sup>
- Ultrafiltrate flow varies inversely with hematocrit, showing a decrease at higher hematocrits and plasma protein concentrations.<sup>6,8</sup> This decrease is at least in part due to concentration polarization within the UFD itself<sup>4,9</sup> as well as increasing COP, which effects a decrease in the primary convective force of ultrafiltration.

In this clinical study, ultrafiltration was utilized primarily during the rewarming period of CPB to concentrate excess circuit volume and achieve hematocrit values acceptable for CPB termination. Consequently, both blood temperature and hematocrit were changing throughout the ultrafiltration period. The change in TMP was controlled for by evaluating the ultrafiltration rate (ml/min/mmHg) rather than the ultrafiltrate flow alone. However, the decrease in UFR due to either increasing protein concentration and COP (paralleling increasing hematocrit) or lower blood temperature was not controlled for. These uncon-



**Figure 4:** Net increase in plasma hemoglobin concentration during ultrafiltration.

TIME: Duration of ultrafiltration (minutes)

TMP: Transmembrane pressure (mmHg)

# UNITS: Number of bank blood units added during ultrafiltration

ULTRAF: Total volume of ultrafiltrate removed (ccs)

trolled variables, along with experimental variability resulted in disparity in the data yielding high, yet consistent, standard deviations with a resultant loss of statistical significance at a 95% confidence level.

Under the test conditions of this study, the Sarns Hemoconcentrator was the most efficient of the three UFDs evaluated with regard to ultrafiltration rate and ease of priming. The higher ultrafiltration rate was presumably due to the larger surface area of the device.

All 3 UFDs produced some degree of hemolysis, which seemed to be related to the TMP. There was no ready explanation regarding the difference in TMP and percent hemolysis of the two Diafilter trials, since both evaluations occurred under similar test conditions (although variation in patient parameters cannot be ruled out). Due to the limited data of this study, further testing is required to verify the percent hemolysis of each UFD.

The blood detected in the ultrafiltrate of the 3 Diafilter units was probably due to a break in one or more of the fibers, although this was visually confirmed in only one case. Rupture of these fibers could occur

during debubbling with a percussion mallet or during shipping and handling.

## References

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1. Messmer, K., Sunder-Plassmann, L., Klovekorn, W.P., et al.: Circulatory Significance of Hemodilution: Rheological Changes and Limitations. *Adv. Microcirc.* 4:1-77, 1972
2. Magilligan, D.J., Holt, D.W.: *Hemodilution in Cardiopulmonary Bypass Surgery*. Monograph published by Bard Cardiopulmonary Division, Santa Ana, CA, 92705 (#387-3/83).
3. Walpoth, B.H., von Albertini, B.: Ultrafiltration in Cardiac Surgery. *J. Extra-Corpor. Technol.* 16:71, 1984.
4. Tamari, Y., Nelson, R., Levy, R., et al.: Conversion of Dilute Pump Blood to Whole Blood by Single Pass Ultrafiltration. *J. Extra-Corpor. Technol.* 15:126-132, 1983.
5. Tamari, Y., Nelson, R., Levy, R., et al.: Concentration of Blood in the Extracorporeal Circuit Using Ultrafiltration. *J. Extra-Corpor. Technol.* 15:133-142, 1983.
6. "Package Insert Hemocor Hemoconcentrator" published by Minntech Corp., Minneapolis, MN, 55441 (#67099-000/A-5/85).
7. "Omnis Surgical Hemoconcentrator Package Insert" published by Omnis Surgical Inc., Deerfield, IL, 60015 (#8-19-8-343-2/85).
8. "Amicon Operating Instructions Diafilter-30 Hemofilter" published by Amicon Corporation, Danvers, MA, 01923 (#1-233A-1/83).
9. Colton, C.K., Henderson, L.W., Ford, C.A., et al.: Kinetics of Hemodiafiltration. I. In Vitro Transport Characteristics of a Hollow-Fiber Blood Ultrafilter. *J. Lab. Clin. Med.* 85:355-371, 1975.

## Questions from the Audience

*Question: Jack Olds of Springfield, MA:* I noticed that you used quite high transmembrane pressures. At our institution we don't use any negative pressure for both the Amicon and Hemocor. With the Hemocor particularly, we found that very good ultrafiltration results with much lower flow rates than you use. We use about 250cc flow per minute and with no vacuum attached, we've seen no hemolysis produced this way.

*Response:* Right, these devices are very efficient. Depending on your situation and how quickly you want to take fluid off, most of the time you can get by without any negative pressure, indeed. I feel this would reduce your hemolysis. Again, if you want to take more fluid off quickly you can always attach a suction line.

*Question: Larry Shells, Savannah, GA:* How do you quantitate among the three units—the amount of concentrated plasma hemoglobin?

*Response:* I don't understand your question.

*Question:* The units don't spill plasma hemoglobin. You concentrated that also. How did you quantitate the difference?

*Response:* We didn't measure plasma hemoglobin in the ultrafiltrate. We measured plasma hemoglobin in the blood.

*Question:* I know, but you're concentrating it also. How did you measure the difference among the three units?

*Response:* We measured both hematocrit and plasma hemoglobin values at the same time and we accounted for the concentration effect by the percent increase in hematocrit as compared to the percent increase in plasma hemoglobin. The difference is increasing plasma hemoglobin. Does that answer your question? We compared percent increase in plasma hemoglobin to percent increase in hematocrit.

*Question: Steve Murphy, Southern California:* Do you always have negative pressure on the different units? And what was your average pressure?

*Answer:* Yes, we use 200 millimeters of negative pressure on the ultrafiltrate line, and all the units tested. We just did that in all the cases to keep the testing conditions similar.

*Question:* Was there any difference as far as not having any negative pressure—or high negative pressures at, say, 600 millimeters?

*Response:* We never tested that.

*Question:* Nancy Acorn, San Francisco, CA: A couple of years ago Mr. Hurley pointed out to me an inherent hazard in your perfusion circuit. This is something we see in people's cardioplegic circuits all the time. If you're using an arterial line membrane oxygenator and you have pressurized blood coming out of your oxygenator into another pumphead, and if for any reason your basic arterial pumphead should stop—say a low flow situation, inherent alarm—your arterial pump head stops, your diafilter or hemoconcentrator pumphead keeps going. You can easily draw air across your membrane and cause an embolus situation. We have found in our situation, in using hemoconcentrators, that the passive pressure without an intermittent pumphead is totally adequate to get adequate water taken off through your hemoconcentrator.

*Response:* That's true. However, in that type of situation you can't really control flow to the device, which we wanted in order to maintain a constant for these testing conditions. It's true you can pull gas across the membrane if your flow through the device continues without arterial flow. It's just something you have to be cognizant of.

*Question:* So do you set this up just for an event study, or would you use it clinically?

*Response:* We used this clinically also.

*Comment—person asking the question:* I would say that we never have had this, especially with a quarter inch takeoff line. We have always had adequate passive flow, even though you say you can't regulate it. We have always had adequate passive flow to take off as much water as we want to, without having that inherent hazard.

*Response:* Of course, I'm not necessarily advocating our setup. I'm just explaining what we used. These devices are efficient enough in that you can get adequate ultrafiltration in the situation you described.

*Question:* Yehuda Tamari, New York, NY: With membrane oxygenators it may be possible to just draw your blood from the venous reservoir and then you overcome that problem. The other thing is that hemolysis can be caused if you stop the blood flow and maintain the vacuum and then restart the flow. So one has to be careful when using the vacuum to make sure they shut it off before they shut off the blood.

*Response:* I didn't mention this, mostly because of time constraints, but during our testing, when we were not ultrafiltrating we clamped the ultrafiltrate line and we just maintained a slow flow through the device to prevent any settling and stagnation of blood in the fibers.