

# Clinical Evaluation of the Sorin Synthesis™ Oxygenator With Integrated Arterial Filter

Gerard J. Myers, CCP; Ken Gardiner, CPC; Steve N. Ditmore, CPC; Wilfred J. Swyer, CCP; Chris Squires, CPC; David R. Johnstone, CCP; Clarie V. Power, CPC; Lance B. Mitchell, CPC; Jan E. Ditmore, CPC; Bill Cook, CCP

Cardiovascular Perfusion Services, QEII Health Sciences Center, Halifax, Nova Scotia

Presented at the 42nd International Conference of the American Society of Extra-Corporeal Technology, Hollywood, Florida, 2004

**Abstract:** The use of arterial line filters has long been a standard of practice in the field of cardiopulmonary bypass. Sorin Biomedica has designed an adult hollow-fiber oxygenator that not only incorporates their Mimesys® biomimicry coating technology but also has a 40-micron arterial filter as an integrated component of this unique membrane oxygenator. We did a prospective, randomized clinical trial of 54 Synthesis® coated oxygenators and compared them with 54 uncoated Monolith Pro® oxygenators, the latter of which incorporated an external arterial line filter with a standard bypass loop. There were few statistically significant differences found between the Synthesis® group and the Monolith group with regard to pressure differentials, hemodynamic resistance, and platelet drop. The Synthesis® oxygenator

did require less priming volume, but the amount was not significant. Platelet counts with the Phosphorylcholine coated Synthesis oxygenators, using crystalloid perfusates, was similar to our previously published data on platelet protection and Albumin perfusates. We conclude that the Sorin Synthesis® oxygenator appears to have better flow characteristics than the Monolith oxygenator, with the potential for lower priming volumes. The most clinically significant benefit comes from the elimination of the arterial filter bypass loop and the avoidance of inverting the arterial filter during priming. **Keywords:** synthesis, phosphorylcholine, coated, oxygenators, arterial filter, bypass loop, platelets, pressure excursion, adult, cardiopulmonary. *JECT. 2005; 37:201–206*

Adult Perfusion centers have been using arterial blood filters for the past couple of decades. They are designed with patient safety in mind by preventing the transmission of micro/macro air and particulate emboli into the bypass patient (1,2). These screen filters are made by several manufacturers in a variety of different designs, all of which are connected to the oxygenator by a length of 3/8" tubing. With the exception of the Quart®, by Jostra (3), all arterial filters are positioned with a 3/8" bypass loop, which allows retrograde deairing of the filter and still allows the user to bypass the filter if it becomes unusable over a period of time. Most modern arterial filters are made of a pleated polyester material and have a range of effective surface areas from 600 to 800 cm<sup>2</sup> (2,4).

The Synthesis® (Sorin Biomedica, Italy) arterial filter also is made of a polyester material but is a single screen, nonpleated filter, with an effective surface area of 400 cm<sup>2</sup>. Through the integration of an unpleated 40-micron screen arterial filter around the oxygenator itself, the Synthesis oxygenator eliminates the use of connection tubing and the arterial filter bypass loop. This integrated arterial line filter was designed to allow antegrade debubbling and reduce priming volumes while eliminating the need to invert it during priming (5).

The Synthesis oxygenator has been in clinical use in Europe since the spring of 2002, and was released by the Federal Drug Administration and Health Canada for use in North America in 2003. Therefore, the purpose of this study was to evaluate the hemodynamics, gas transfer, and performance of the Synthesis oxygenator by comparing it with a control (the Monolith Pro) under varying clinical conditions during adult cardiopulmonary bypass (CPB).

Both the control and the Synthesis oxygenators used in this study were made from polypropylene material, each with a suggested maximum blood flow of 8.0 LPM. How-

Address correspondence to: Gerard J Myers, RRT, CCP, Cardiovascular Perfusion Services, Cardiac OR, NHI Campus, QEII Health Sciences Center, PO Box 9000, Halifax, Nova Scotia Canada. B3K 6A3. E-mail: edit@ns.sympatico.ca

The senior author has stated that authors have reported no material, financial or other relationship with any healthcare-related business or other entity whose products or services are discussed in this paper.

ever, only the Synthesis oxygenator was coated with a biocompatible, phosphorylcholine coating called Mimesys®. Phosphorylcholine (PC) is a nonheparin, synthetic phospholipid-based polymer that mimics the outer surface of biological cell membranes, making it relatively biologically inert to circulating blood (6,7).

The heat exchanger surface area of the Synthesis (0.14 m<sup>2</sup>) was slightly smaller than the control (0.17 m<sup>2</sup>) but under the manufacturers in vitro laboratory conditions, they both held the same heat exchanger coefficients of 0.68. The membrane surface area in the Synthesis (2.0 m<sup>2</sup>) also was slightly smaller than that of the control (2.2 m<sup>2</sup>). Priming volume of the Synthesis was 430 mL, which included the oxygenator, heat exchanger, and arterial filter. Priming volume of the control was 286 mL, which only included the oxygenator and heat exchanger (5,6). In addition, priming volume of the Medtronic Affinity® arterial filter and bypass loop used with the control was 250 mL (in vitro measurements).

Under the manufacturers in vitro conditions (flow: 6 LPM, FiO<sub>2</sub>: 1.0, V/Q ratio: 1.0, and temperature: 37°C), the oxygen transfer was 370 mL/min/FiO<sub>2</sub> in the control and 410 mL/min/FiO<sub>2</sub> in the Synthesis oxygenator (5,6).

## MATERIALS AND METHODS

After divisional review, it was felt that institutional review board approval and patient consent were not required for these oxygenator evaluations in our cardiac surgical program. A total of 54 Mimesys®-coated Synthesis® oxygenators with hard-shell venous reservoirs and 54 uncoated Monolyth Pro oxygenators (Sorin Biomedica, Italy) with hard-shell venous reservoirs and external Affinity® arterial blood filters (Medtronic Inc., Minneapolis, MN) were evaluated for blood flow rate, transmembrane pressures (TMP), hemodynamic resistance (HDR), priming volume, plasma-free hemoglobin, and platelet loss. There were no exclusion criteria for this trial. Synthesis and control oxygenators were assigned to individual operating rooms and were assigned randomly to patients on a daily basis by booking clerks.

All oxygenators and filters were flushed with CO<sub>2</sub> for a minimum of 3 min before priming. The oxygenator's performance was measured by calculating the Oxygen Transfer ( $[\{\text{Arterial-Venous Saturation}\} \times 1.34 \times \text{actual hemoglobin} \times \text{blood flow}]/100$ ) and Carbon Dioxide Transfer ( $[\text{PaCO}_2 \times \text{gas flow rate}]/0.863$ ). There were no changes to our institutional perfusion practices during this trial period, and all cases were done using the Sorin CAPS, Sorin SIII (Sorin Biomedica, Italy) heart lung machines and the Sorin Data Management System. Unlike previously published reports on oxygenator trials (8), this trial did not exclude cardiotomy suction blood for any of the cases presented. Temperature control was maintained using the

Model 400MR Hemotherm (Cincinnati Sub Zero, Cincinnati, OH). The Sorin CSC14 blood cardioplegia (Sorin Biomedica, Italy) was used at a ratio of 4:1 in all cases.

As part of the anesthetic prebypass medication regimen in the Monolyth Pro (Control) group, 6 patients (11%) received Trasylol® (Aprotinin; Bayer, Inc., Pittsburgh, PA), 37 patients (69%) received Cyklokapron® (Tranexamic Acid; Pharmacia & Upjohn, Inc., Toronto, Canada), no patients received Amicar® (Epsilon Aminocaproic Acid; Wyeth-Ayerst, Toronto, Canada), and 27 patients (50%) received Diprivan® (propofol; Zeneca Pharma, Ontario, Canada). In the Synthesis group, 4 patients (7%) received Trasylol®, 36 patients (67%) received Cyklokapron®, 2 patients (4%) received Amicar®, and 27 patients (50%) received Diprivan® (Table 1).

In both the Synthesis and the control groups, the volume used to fill oxygenator, filter, and arteriovenous loop (priming volume) consisted of Normosol R® (Abbott Laboratories, Saint-Laurent, Québec, Canada) and 10,000 units of porcine heparin (Hepalean®, Organon Tunica, Ottawa, Ontario, Canada). In addition to the priming volume heparin, all patients received the usual anesthesia loading dose of heparin between 300 and 350 units/kg before bypass. Activated Coagulation Time (ACT) was measured using the Medtronic ACTII machine (Medtronic Inc.), with target values for ACT > 480 s. Patient demographics for all groups are found in Table 2. Both groups had the use of identical equipment, techniques, sampling, and measurements performed. The patient's preoperative hematologic profile was obtained before cardiopulmonary bypass (Table 3).

Before going on bypass, all perfusates were kept at normothermic temperatures and circulated through the arteriovenous loop at 4.0 LPM. From this flow, the difference between premembrane and postmembrane pressures was used to determine the TMP, as well as the HDR (TMP divided by blood flow rate) in both the synthesis and control groups. The latter parameters were repeated at periods of 10, 30, 50, and 70 min during CPB. Patient nasopharyngeal temperatures were measured at three times (10, 50, and 70 min) during the trial.

The results for hematology (plasma-free hemoglobin, blood gases, platelets, WBC, hemoglobin/hematocrit, and ACT) were drawn during the first 10 min of CPB in both groups studied. The findings were statistically analyzed for relevance.

**Table 1.** Anesthetic drugs.

	Control (%)	Synthesis (%)
Aprotinin ( <i>Trasylol</i> )	11	7
Epsilon aminocaproic acid ( <i>Cyklokapron</i> )	0	4
Tranexamic acid ( <i>Amicar</i> )	69	67
Propofol ( <i>Diprivan</i> )	50	50

**Table 2.** Patient demographics.

	Control	Synthesis	<i>p</i> Value
Age (yrs)	65.2 ± 12	66.5 ± 26	NS
Weight (kg)	83 ± 17	82 ± 13	NS
BSA (m <sup>2</sup> )	1.96 ± 0.2	1.95 ± 0.7	NS
Gender (M/F) (%)	72/28	74/26	

NS, not significant.

**Table 3.** Preoperative hematology.

	Control	Synthesis	<i>p</i> Value
Pre-Plts (mm <sup>3</sup> )	240 ± 98	223 ± 77	NS
Pre WBC (mm <sup>3</sup> )	7.5 ± 4.6	7.5 ± 2.8	NS
Pre Hct (%)	0.38 ± .06	0.38 ± .05	NS

NS, not significant.

## STATISTICS

All statistical analysis was performed using Microsoft Excel 2000 Data Analysis tool pack. Values are expressed as plus or minus standard deviation of the mean. Data for blood flow, resistance, pressure drop and temperature were analyzed with analysis of variance: two factor with replication, and all others were analyzed using two-tailed Student *t* test assuming equal and unequal variances. Platelet results were not corrected for hemodilution. For all tests, *p* values of ≤ 0.05 were considered statistically significant.

## RESULTS

Using the SIII Microbubble Detection system, there was no microbubble activity noted throughout the course of bypass in either of the two groups. In the control group, with a mean bypass time of 131 ± 61 min and a mean cross clamp time of 92 ± 50 min, 37 cases were coronary artery bypass grafts (CABG), 7 cases were a combination of valves and CABG, 6 were valves only, and 1 case was a right ventricular outflow tract resection. In the Synthesis group, with a mean bypass time of 132 ± 5 min and a mean cross clamp time of 87 ± 44 min, 44 cases were CABG, 7 cases were a combination of valves and CABG, 2 cases were valves only, and 1 case was an atrial myxoma (Table 4). The mean arterial blood temperature at 10 min on

**Table 4.** Procedures.

	Control	Synthesis
Pump time (min)	131 ± 61	132 ± 55
Clamp time (min)	92 ± 50	87 ± 44
Procedures	73% CABG 14% Valves/CABG 12% Valves 2% Others	91% CABG 13% Valves/CABG 4% Valves 2% Others

CABG, coronary artery bypass grafting.

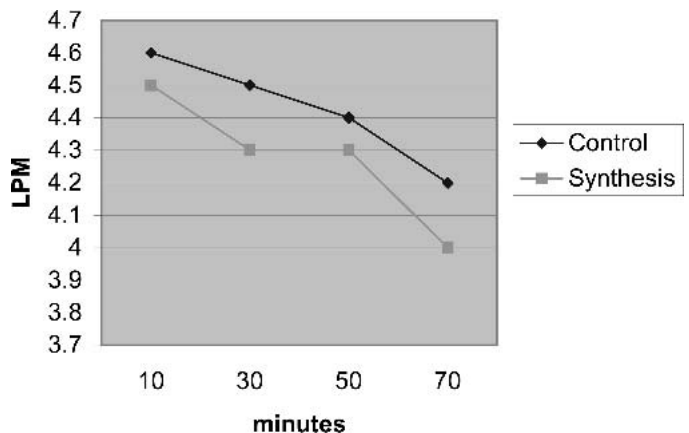
bypass was also 34.1 ± 0.9°C in the control group and 34.1 ± 0.8°C in the Synthesis group.

There was no significant difference in pump flow rate noticed between the two groups during bypass at the 10, 30, 50, or 70-min mark (Figure 1). Before bypass, the mean prebypass TMP in the control group was measured at 40.1 ± 14.0 mmHg, and in the Synthesis® group at 41.2 ± 7.0 mmHg. There were statistically significant differences noted in the TMP at 10 min and 30 min after going on bypass (Figure 2). Ten minutes after bypass was initiated, the TMP in the control group was 88.4 ± 35 mmHg and the Synthesis group was 80.5 ± 19 mmHg (*p* = 0.03). At 30 min, the TMP in the control group was 87.1 ± 31 mmHg and the Synthesis group was 75.1 ± 19 mmHg (*p* = 0.004). At 50 min, the TMP in the control group was 82.2 ± 28 mmHg and the Synthesis group was 75.5 ± 20 mmHg (*p* = ns). After 70 min of bypass, the TMP in the control group was 80.2 ± 8.4 mmHg and the Synthesis group was 71.6 ± 15 mmHg (*p* = ns).

There was a significant difference in HDR between the two groups at the 10-min, 30-min, and 50-min point (Figure 3). At 10 min on bypass, the HDR in the control group was 18.8 ± 6.4 mmHg and the Synthesis group was 17.5 ± 2.3 mmHg (*p* = 0.03). At 30 min on bypass, the HDR in the control group was 19.0 ± 5.0 mmHg and the Synthesis group was 17.4 ± 2.3 mmHg (*p* = 0.003). At 50 min on bypass, the HDR in the control group was 18.4 ± 3.9 mmHg and the Synthesis group was 17.1 ± 3.0 mmHg (*p* = 0.009). As with the TMP, after 70 min of bypass the HDR did not reach statistical significance.

After 10 min on CPB, there was no statistically significant difference in plasma-free hemoglobin, WBC, hemoglobin/hematocrit, or ACT (Table 5). After 10 min of CPB, the drop in platelets did reach significance between the two groups (*p* = 0.01), with a 43.0 ± 17% drop in the control group and only a 36.6 ± 17% in the Synthesis group.

High-pressure excursion (HPE) is the occurrence of

**Figure 1.** Pump flow rates.

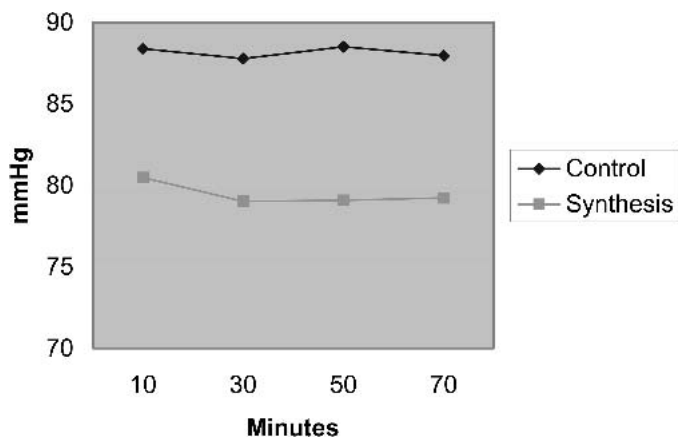


Figure 2. Transmembrane pressure.

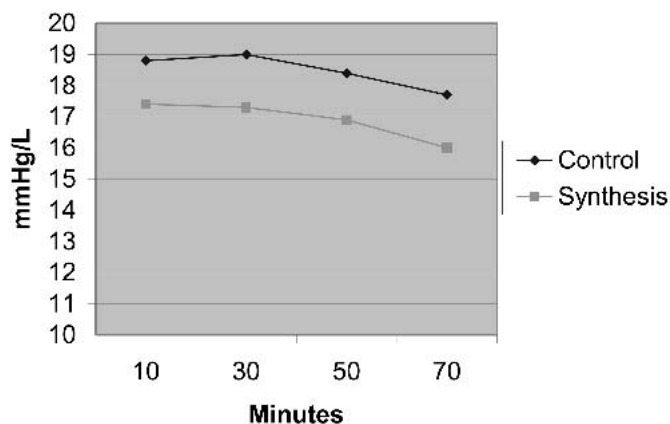


Figure 3. Hemodynamic resistance.

sudden increases in premembrane pressures and membrane pressure differentials, which occur more frequently in the absence of albumin and the presence of uncoated extracorporeal circuitry. The occurrence of HPE has been previously described in both coated and uncoated oxygenators (9). There were three incidents of HPE in the uncoated control group and none in the Synthesis group. Because of the effects HPE has on platelets and pressures, all data collected in the three HPE cases were excluded from the data analysis.

As shown in Table 5, priming volume for the control group was a mean of  $1901 \pm 156$  mL, and  $1719 \pm 216$  mL for the Synthesis group ( $p = \text{ns}$ ). Oxygenator performance is examined in Table 6. Oxygen Transfer was  $179 \pm 35.9$  mL $\text{O}_2$ /min/ $\text{FiO}_2$  in the control group and  $160 \pm 38.1$  mL $\text{O}_2$ /min/ $\text{FiO}_2$  in the Synthesis group ( $p = \text{ns}$ ). Carbon dioxide transfer was  $111 \pm 28.0$  mL $\text{CO}_2$ /min in the control and  $106.0 \pm 26.8$  mL $\text{CO}_2$ /min in the Synthesis group ( $p = \text{ns}$ ).

The final parameters measured in this study were the blood gas analysis (Table 7). The  $\text{FiO}_2$  and gas/blood flow ratios were similar in both groups ( $p = \text{ns}$ ). Arterial  $\text{PO}_2$  was  $252.0 \pm 68.0$  mmHg in the control group and  $293 \pm$

Table 5. Hematology on CPB.

	Control	Synthesis	<i>p</i> Value
Platelet decrease (%)	$43.0 \pm 17$	$36.6 \pm 17$	0.01
Plasma-free Hgb (g/dL)	$10.5 \pm 9.0$	$9.9 \pm 8.3$	NS
WBC ( $\text{mm}^3$ )	$4.3 \pm 2.6$	$4.1 \pm 1.9$	NS
Hemoglobin (g/dL)	$7.7 \pm 14.4$	$7.8 \pm 14.1$	NS
Hematocrit (%)	$22 \pm .04$	$23 \pm .04$	NS
ACT (sec)	$725 \pm 175$	$680 \pm 216$	NS
HPE	3	0	

ACT, activated clotting time; HPE, high-pressure excursion; NS, not significant; WBC, white blood cells.

Table 6. Oxygenator performance.

	Control	Synthesis	<i>p</i> Value
Prime volume (mls)	$1901 \pm 156$	$1719 \pm 216$	NS
$\text{FiO}_2$ (%)	$54.0 \pm .08$	$53.0 \pm .05$	NS
$\text{O}_2$ transfer (mL/min/ $\text{FiO}_2$ )	$179 \pm 35.9$	$160 \pm 38.1$	NS
$\text{CO}_2$ transfer (mL/min)	$111 \pm 28.0$	$106 \pm 26.8$	NS
Gas/Blood flow ratio	$0.55 \pm 0.1$	$0.57 \pm 0.1$	NS

NS, not significant.

Table 7. Blood gas results.

	Control	Synthesis	<i>p</i> Value
$\text{PaO}_2$ (mmHg)	$252 \pm 68$	$293 \pm 65$	0.002
$\text{PaCO}_2$ (mmHg)	$38 \pm 5$	$37 \pm 4$	NS
Art sat (%)	$98 \pm 1.0$	$99 \pm 0.6$	NS
Ven sat (%)	$78 \pm 5.3$	$81 \pm 7.1$	0.01

$65.0$  mmHg in the Synthesis group ( $p = 0.001$ ). The mean  $\text{PaCO}_2$  was  $38.0 \pm 5.0$  mmHg in the control group and  $37.0 \pm 4.0$  mmHg in the Synthesis group ( $p = \text{ns}$ ). Arterial saturations were  $98 \pm 1.0\%$  in the control group and  $99 \pm 0.6\%$  in the Synthesis group ( $p = \text{ns}$ ). The venous saturations were  $78 \pm 5.3\%$  in the control group and  $81 \pm 7.1\%$  in the Synthesis group ( $p = 0.01$ ). All patients in both groups had uneventful postoperative courses and were subsequently discharged to home.

## DISCUSSION

After flushing with  $\text{CO}_2$  and gravity priming of the Synthesis oxygenator, the integral arterial filter should be pump primed slowly (approx. 50 mL/min) to allow initial fluid breakthrough and allow the  $\text{CO}_2$  to be completely evacuated from the filter housing.

Results found in this study (Figures 2 and 3) indicate that coating Synthesis® oxygenators with PC material does not interfere with blood flow characteristics. Considering that there was no significant difference in blood flow rate and temperature (Figure 4) between the two groups, significant changes in TMP and HDR did occur through the first 50 min of bypass. This may be indicative of better flow characteristics in the Synthesis oxygenator because

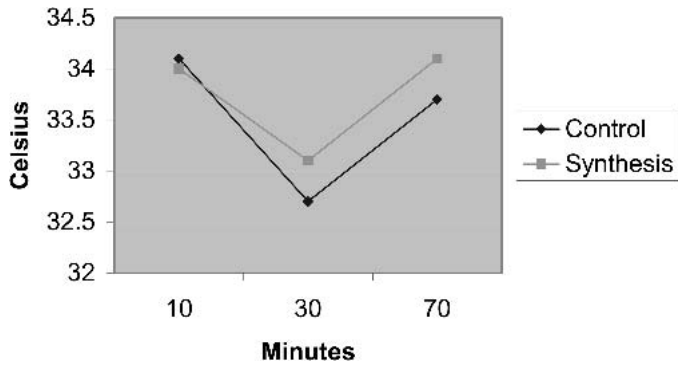


Figure 4. Temperature.

the differences were consistent throughout the trial period, but did not reach statistical significance at 70 min.

When compared with the control group, there was no significant difference found in the Synthesis group with regards to patient demographics, temperature,  $O_2/CO_2$  transfer,  $FiO_2$ , hemoglobin/hematocrit, pump flow rates and gas/blood flow ratio (Tables 2, 4, 5, and 6). Statistical significance was reached when evaluating intraoperative  $PaO_2$  and venous saturations (Table 7). However, improvements in venous saturations and arterial  $PaO_2$  may not be a reflection of the oxygenator's performance but rather the result of individual patient oxygen consumptions, which were not measured in this study.

As indicated in our previously published studies on PC-coated and uncoated membranes, the improved platelet counts were a reflection of biological surface coatings (9,10) and not a reflection of the membranes performance. One of the limitations of this trial was the amount of times platelet counts were measured throughout the course of CPB.

Because the reported incidence of HPE in uncoated CPB surfaces ranges from 0.6% to 4.3%, whereas that in coated surfaces is < 0.4% (10), it was also no surprise that HPE appeared in the uncoated group. HPEs result from the sudden adhesion of platelets to the membranes surface area, which results in increased premembrane pressures, reduced blood flow through the oxygenator, and decreased systemic circulation. This sudden and dramatic interference with blood flow could result in emergency change out of the oxygenator if immediate steps are not taken. In the three cases of HPE that occurred during this trial, the latter was avoided by increasing the  $FiO_2$  to 100%, warming the patient towards 37°C, closing all post-membrane shunts, treating the patients systemic pressure with vasopressor, reducing pump flow rates, and waiting for this transient problem to resolve (10).

Because of the elimination of bypass loops and connecting tubing, the Synthesis oxygenator has to allow for some reduction of priming volume. This was evidenced in our findings with a mean difference of 183 mL between the two groups (Table 6) but was of no statistical significance.

Unfortunately, with 10 perfusionists involved in the study and no required change in institutional practice, this was one phase of the study that may have been influenced by the operator's technique.

One of the true benefits of the Synthesis oxygenator is the elimination of the arterial filter bypass loop. To understand this, we should look at the reasons why bypass loops are used. The first is the ability of the bypass loop to retrograde prime the arterial filter. This was a technique suggest by the manufacturers more than 25 years ago. In actual fact, there is no documented evidence to support the necessity for retrograde priming of modern arterial filters. They can be easily antegrade primed first and then inverted for residual deairing while circulating through the A-V loop.

The second reason involves trouble shooting during CPB. The thought process is if the arterial filter develops a problem on bypass (e.g., clot, debris, high pressure), the perfusionist can release the bypass loop clamp and allow the operator to continue on with CPB by diverting flow around the filter. However, the reality is, if clotting, debris, etc. occur above the clamp, the bypass loop should never be opened because these problems could be sent directly to the patient's head. In addition, we have been unable to find anything in the literature to indicate what exactly the composition of that stagnant pool of blood above the bypass loop clamp contains, especially after two or three hours of bypass. The question then arises, if it is not needed for priming the filter and not safe to open in emergency situations, why should it be there? The answer is that it should not.

## CONCLUSION

There have been many changes in oxygenator technology (11), heart lung machine design, and surface coating biologics during the past 25 years. Most of these changes laid down the framework for improved patient outcomes. However, when it comes to arterial filters, to this day we still place a clamp on the bypass loop tubing throughout the case. The Synthesis oxygenator finally has addressed this issue and eliminated the bypass loop.

Statistically speaking, there were few strongly significant areas of difference between the two oxygenators. But the clinical advantages the Synthesis takes into the operating room is its better visibility for low volume operation and its quick connect holder for the water outlets. Further improvements in the Synthesis technology also can be found in the oxygenator's biomimicry coating, as evidenced by the significant numbers reached with platelet count. The Sorin Synthesis oxygenator, with integrated arterial filter, is a reliable and efficient oxygenator for cardiopulmonary bypass, which also eliminates the potential for problems associated with the use of arterial filter bypass loops.

**ACKNOWLEDGMENTS**

Sorin Group provided financial support for laboratory analysis of data obtained in this clinical trial.

**REFERENCES**

1. Waaben J, Sorensen HR, Andersen U, et al. Arterial line filtration protects brain microcirculation during cardiopulmonary bypass in the pig. *J Thorac Cardiovasc Surg.* 1994;107:1030–5.
2. Martens S, Dietrich M, Pietrzyk R, et al. Elimination of microbubbles from the extracorporeal circuit: dynamic bubble trap versus arterial filter. *Int J Artif Organs.* 2004;27:55–9.
3. Mueller XM, Tevaearai HT, Jegger D, et al. Ex vivo testing of the Quart arterial line filter. *Perfusion.* 1999;14:481–7.
4. Edmunds LH, Williams W. Microemboli and the use of filters during cardiopulmonary bypass. In Utley JR, ed. *Pathophysiology and Techniques of Cardiopulmonary Bypass.* Baltimore: Williams & Wilkins; 1983:109–12.
5. Sorin Biomedica Cardio. Product Monograph on Synthesis: Sorin Biomedica, Italy, 2002.
6. Sorin Biomedica Cardio. Product Monograph on Monolyth Pro: Sorin Biomedica, Italy, 1995.
7. Hayward JA, Durrani AA, Lu Y, Clayton CR, Chapman D. Biomembranes as models for polymer surfaces. IV. ESCA analyses of a Phosphorylcholine surface covalently bound to hydroxylated substrates. *Biomaterials.* 1986;7:252–8.
8. Segers PA, Heida JF, de Vries I, et al. Clinical evaluation of nine hollow-fiber membrane oxygenators. *Perfusion.* 2001;16:95–106.
9. Myers GJ, Johnstone DR, Swyer WJ, et al. Evaluation of Mimesys® Phosphorylcholine (pc) coated oxygenators during cardiopulmonary bypass in adults. *J Extra Corpor Technol.* 2003;35:6–12.
10. Myers GJ, Weighell PR, McCloskey BJ, et al. High pressure excursions: a retrospective patient profile of 31 cases. *J Extra Corpor Technol.* 2003;35:127–32.
11. Dubois J, Jamaer L, Mees U, et al. Ex vivo evaluation of a new neonatal/infant oxygenator: comparison of the Terumo CAPIOX Baby RX with Dideco Lilliput 1 and Polystan Safe Micro in the piglet model. *Perfusion.* 2004;19:315–21.