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

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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 Monolyth 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 Monolyth 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 Monolyth 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.

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

The heat exchanger surface area of the Synthesis (0.14 m²) was slightly smaller than the control (0.17 m²) 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 m²) also was slightly smaller than that of the control (2.2 m²).

Priming volume of the Synthesis was 430 mL, which in-
cluded the oxygenator, heat exchanger, and arterial filter.
Priming volume of the control was 286 mL, which only
cluded the oxygenator and heat exchanger (5,6). In ad-
dition, 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, FiO₂: 1.0, V/Q ratio: 1.0, and temperature: 37°
C), the oxygen transfer was 370 mL/min/FiO₂ in the control
and 410 mL/min/FiO₂ in the Synthesis oxygenator (5,6).

**MATERIALS AND METHODS**

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

All oxygenators and filters were flushed with CO₂ for a
minimum of 3 min before priming. The oxygenator’s per-
formance was measured by calculating the Oxygen Trans-
fier ([Arterial-Venous Saturation] × 1.34 × actual hemo-
globin × blood flow]/100) and Carbon Dioxide Transfer
([PaCO₂ × gas flow rate]/0.863). There were no changes to
our institutional perfusion practices during this trial pe-
riod, 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 pub-
lished reports on oxygenator trials (8), this trial did not
exclude cardiomyopathy. Temperature control was maintained using the

**Table 1.** Anesthetic drugs.

<table>
<thead>
<tr>
<th>Drug</th>
<th>Control (%)</th>
<th>Synthesis (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aprotinin (Trasylol)</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Epsilon amnacomproic acid (Cyklokapron)</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Tranexamic acid (Amicar)</td>
<td>69</td>
<td>67</td>
</tr>
<tr>
<td>Propofol (Diprivan)</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

As part of the anesthetic prebypass medication regimen
in the Monolynth Pro (Control) group, 6 patients (11%)
received Trasylol® (Aprotinin; Bayer, Inc., Pittsburgh,
PA), 37 patients (69%) received Cyklokapron® (Tranex-
amic 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 Cyklo-
kapron®, 2 patients (4%) received Amicar®, and 27 pa-
tients (50%) received Diprivan® (Table 1).

In both the Synthesis and the control groups, the vol-
ume used to fill oxygenator, filter, and arteriovenous loop
(priming volume) consisted of Normosol R® (Abbott
Laboratories, Saint-Laurent, Quebec, Canada) and 10,000
units of porcine heparin (Hepalean®, Organon Tunica,
Ottawa, Ontario, Canada). In addition to the priming vol-
ume heparin, all patients received the usual anesthe-
sis loading dose of heparin between 300 and 350 units/kg
before bypass. Activated Coagulation Time (ACT) was mea-
sured using the Medtronic ACTII machine (Medtronic
Inc.), with target values for ACT > 480 s. Patient demo-
graphics 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 nor-
mothermic temperatures and circulated through the arte-
riovenous 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 con-
tral groups. The latter parameters were repeated at peri-
ods of 10, 30, 50, and 70 min during CPB. Patient nasopha-
rangeal 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.
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’s 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 ± 57 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 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 ± 8.0 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 hemoglobulin, 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

**Table 2. Patient demographics.**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Synthesis</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>65.2 ± 12</td>
<td>66.5 ± 26</td>
<td>NS</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83 ± 17</td>
<td>82 ± 13</td>
<td>NS</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>1.96 ± 0.2</td>
<td>1.95 ± 0.7</td>
<td>NS</td>
</tr>
<tr>
<td>Gender (M/F)(%)</td>
<td>72/28</td>
<td>74/26</td>
<td></td>
</tr>
</tbody>
</table>

NS, not significant.

**Table 3. Preoperative hematology.**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Synthesis</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Pts (mm³)</td>
<td>240 ± 98</td>
<td>223 ± 77</td>
<td>NS</td>
</tr>
<tr>
<td>Pre WBC (mm³)</td>
<td>7.5 ± 4.6</td>
<td>7.5 ± 2.8</td>
<td>NS</td>
</tr>
<tr>
<td>Pre Hct (%)</td>
<td>0.38 ± 0.06</td>
<td>0.38 ± 0.05</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS, not significant.

**Table 4. Procedures.**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Synthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump time (min)</td>
<td>131 ± 61</td>
<td>132 ± 55</td>
</tr>
<tr>
<td>Clamp time (min)</td>
<td>92 ± 50</td>
<td>87 ± 44</td>
</tr>
<tr>
<td>Procedures</td>
<td>73% CABG</td>
<td>91% CABG</td>
</tr>
<tr>
<td></td>
<td>14% Valves/CABG</td>
<td>13% Valves/CABG</td>
</tr>
<tr>
<td></td>
<td>12% Valves</td>
<td>4% Valves</td>
</tr>
<tr>
<td></td>
<td>2% Others</td>
<td>2% Others</td>
</tr>
</tbody>
</table>

CABG, coronary artery bypass grafting.
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 ± 156 mL, and 1719 ± 216 mL for the Synthesis group (p = ns). Oxygenator performance is examined in Table 6. Oxygen Transfer was 179 ± 35.9 mL/O2/min/FiO2 in the control group and 160 ± 38.1 mL/O2/min/FiO2 in the Synthesis group (p = ns). Carbon dioxide transfer was 111 ± 28.0 mL/min in the control and 106 ± 28.0 mL/min in the Synthesis group (p = ns).

The final parameters measured in this study were the blood gas analysis (Table 7). The FiO2 and gas/blood flow ratios were similar in both groups (p = ns). Arterial PO2 was 252.0 ± 68.0 mmHg in the control group and 293 ± 65.0 mmHg in the Synthesis group (p = 0.001). The mean PaCO2 was 38.0 ± 5.0 mmHg in the control group and 37.0 ± 4.0 mmHg in the Synthesis group (p = ns). Arterial saturations were 98 ± 1.0% in the control group and 99 ± 0.6% in the Synthesis group (p = ns). The venous saturations were 78 ± 5.3% in the control group and 81 ± 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 CO2 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 CO2 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

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**Table 5. Hematology on CPB.**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Synthesis</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platelet decrease (%)</td>
<td>43.0 ± 17</td>
<td>36.6 ± 17</td>
<td>0.01</td>
</tr>
<tr>
<td>Plasma-free Hgb (g/dL)</td>
<td>10.5 ± 9.0</td>
<td>9.9 ± 8.3</td>
<td>NS</td>
</tr>
<tr>
<td>WBC (mm³)</td>
<td>4.3 ± 2.6</td>
<td>4.1 ± 1.9</td>
<td>NS</td>
</tr>
<tr>
<td>Hemoglobin (g/dL)</td>
<td>7.7 ± 14.4</td>
<td>7.8 ± 14.1</td>
<td>NS</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>22 ± .04</td>
<td>23 ± .04</td>
<td>NS</td>
</tr>
<tr>
<td>ACT (sec)</td>
<td>725 ± 175</td>
<td>680 ± 216</td>
<td>NS</td>
</tr>
<tr>
<td>HPE</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

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

**Table 6. Oxygenator performance.**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Synthesis</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime volume (mls)</td>
<td>1901 ± 156</td>
<td>1719 ± 216</td>
<td>NS</td>
</tr>
<tr>
<td>FiO2 (%)</td>
<td>54.0 ± .08</td>
<td>53.0 ± .05</td>
<td>NS</td>
</tr>
<tr>
<td>O2 transfer (mL/min/FiO2)</td>
<td>179 ± 35.9</td>
<td>160 ± 38.1</td>
<td>NS</td>
</tr>
<tr>
<td>CO2 transfer (mL/min)</td>
<td>111 ± 28.0</td>
<td>106 ± 26.8</td>
<td>NS</td>
</tr>
<tr>
<td>Gas/Blood flow ratio</td>
<td>0.55 ± 0.1</td>
<td>0.57 ± 0.1</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS, not significant.

**Table 7. Blood gas results.**

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Synthesis</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO2 (mmHg)</td>
<td>252 ± 68</td>
<td>293 ± 65</td>
<td>0.002</td>
</tr>
<tr>
<td>PaCO2 (mmHg)</td>
<td>38 ± 5</td>
<td>37 ± 4</td>
<td>NS</td>
</tr>
<tr>
<td>Art sat (%)</td>
<td>98 ± 1.0</td>
<td>99 ± 0.6</td>
<td>NS</td>
</tr>
<tr>
<td>Ven sat (%)</td>
<td>78 ± 5.3</td>
<td>81 ± 7.1</td>
<td>0.01</td>
</tr>
</tbody>
</table>
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