Original Article

Reduction in Homologous Blood Transfusions Using a Low Prime Circuit

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ABSTRACT

Due to a low estimated blood volume, small adults (weight less than 70 kg) undergoing cardiopulmonary bypass (CPB) are at highest risk for low hematocrit and homologous blood transfusion (HBT). To determine whether reductions in HBT could be achieved we compared the use of a low prime circuit (1400 ml) with our standard (2200 ml) cardiopulmonary bypass (CPB) circuit.

Eighty consecutive adult patients (>age 18, <70 kg) undergoing non-emergent CPB were randomly divided into two groups. Group LP (n=40) was the low prime group and group SP (n=40) was the standard prime group. In Group LP, either of two “low prime” hollow fiber membrane oxygenators with a 3/8 X 3/8 inch A-V loop were utilized. Alternately, in Group SP, a larger membrane oxygenator with a 3/8 X 1/2 A-V loop was utilized. Circuits and CPB management were otherwise identical. Excluded from the study were those patients who had bleeding disorders, reoperations, ejection fractions of less than 30% and history of cerebral vascular insufficiency.

Patients were closely matched for age, BSA, gender, preoperative risk and procedure. Mean weight (kg) was less in Group LP (59.2 vs 62.2, P<0.02). Pre-CPB hematocrits (HCT) were similar in both groups. Initial on CPB HCT was higher in Group LP (19.8 vs 18.4, P<0.04). Group LP had a higher frequency of initial on CPB HCTs of 20% or greater (55% vs 33%, P<0.04). Group LP had a lower packed red blood cell (PRBC) transfusion rate on CPB (0.4 vs 0.9 units, P<0.03). Group LP had higher percentage of patients that did not require transfusion on CPB (78% vs 55%, P<0.03). Despite fewer transfusions, Group LP had a higher post CPB HCT (20.6 vs 19.3, P<0.04). A trend was noted with a lower total PRBC transfusion rate in Group LP (1.9 vs 2.4, P=.10). During the entire length of stay, fewer Group LP patients required any homologous transfusion (26/40 versus 34/40, P<0.04). Chest drainage, 24 hour HCT and discharge HCT were similar in both groups. Transfusion of platelets, fresh frozen plasma and cryoprecipitate was similar in both groups. There were no deaths in either group.

Patients with low blood volume are at high risk of homologous transfusion when undergoing CPB. A significant reduction in prime volume appears to be safe, simple and reduces HBTs in these individuals. Prime reduction should be part of a comprehensive multi-modality blood conservation program.

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INTRODUCTION

Tremendous effort and expense have been placed on blood conservation methodology. Decreases in blood usage have been achieved with the use of expensive drugs such as aprotinin, technically complicated autotransfusion and disposables such as heparin coated circuitry (1, 2, 3, 4). Our experience at The New York Hospital-Cornell Medical Center has demonstrated that a majority of smaller patients (less than 70 kg) require homologous blood transfusion (HBT) due to the hemodilution and blood loss associated with cardiopulmonary bypass. Adult patients (greater than age 17 years) weighing less than 70 kg represent approximately 40% of our caseload. Almost 60% of them have required HBT during the intraoperative period. Cosgrove and Utley identified the smaller patients to be at highest risk of HBT (5, 6).

Cardiac surgery groups have the highest demand for blood products in most medical centers (7, 8). It is possible that efforts which reduce these demands can lead to improvements in both patient care and cost containment. In an attempt to reduce homologous blood usage, modifications were made to the standard CPB circuit. Specifically, a low prime oxygenator was substituted for a higher volume unit and the diameter and length of the venous line were decreased.

The oxygenator and arterio-venous loop account for the majority of the pump prime volume. Fortunately, “low prime” oxygenators are available and can be used on both small and large patients. Unfortunately, the 3/8 X 1/2 inch arterio-venous loop has become the standard for adult cardiac surgery. Based on a belief that a 1/2 inch diameter venous line is necessary to provide adequate drainage in adults, excessive hemodilution can result in the small adult patient. Our experience in both the laboratory and with a large series of Jehovah’s Witness patients demonstrated that venous drainage was as good, and possibly improved, with the 3/8 inch arterio-venous loop (3). This change led to a further reduction in prime volume.

MATERIALS AND METHODS

Eighty consecutive adult patients (weight less than 70 kg) undergoing non-emergent CPB were randomly divided into two groups. In group LP (n=40) a low prime, 1400 ml, bypass circuit was utilized. In the control group SP (n=40), our standard prime volume of 2200 ml was used. Excluded from the study were patients requiring emergent surgery or with ejection fractions <30%, preoperative hematocrits <30%, a history of bleeding disorders, or a history of a cerebral vascular accident.

Pump prime constituents were similar in both groups, with the exception of volume of balanced electrolyte solution and albumin (Table 1). Moderate hypothermia with cold blood cardioplegia was utilized for all perfusions. Flow rates throughout bypass ranged from 1.6 l/min/m² up to 2.4 l/min/m². All patients were rewarmed to 35.5°C prior to termination of CPB. Hematocrit triggers were set at 15% during CPB, 19% post CPB and 22% in the intensive care unit. Unless there was evidence of hemodynamic instability or anemia related compromise, triggers were strictly adhered to.

Data was collected during the preoperative, intraoperative
and postoperative periods. Demographic data collected included patient weight, BSA, age, preoperative ejection fraction and procedure type. Determinants of oxygenator performance consisted of oxygen delivery index, lowest core temperature and rewarming time. Several parameters were measured to determine the effects of hemodilution: hematocrits, number of packed red blood cell (PRBC) transfusions and twenty-four hour fluid balance. Hematocrit data was collected prebypass, five minutes after the start of bypass, immediately post bypass and at discharge. The total number of PRBCs was counted during CPB and during the entire length of stay (LOS). Lastly, twenty-four hour fluid balance, chest drainage and weight gain data were calculated.

To reduce the prime of the group LP circuit, two steps were taken. First, a 3/8 inch diameter arterio-venous loop was used (arterial line equals 3/8" X 60", venous equals 3/8" X 78"). Second, either of two "low prime" oxygenators were used (Cobe® Optima and Terumo® Capiox SX). In Group SP, a Cobe Excel membrane oxygenator was used with a 3/8 inch X 1/2 inch arterial-venous loop (arterial line equals 3/8" X 80", venous line equals 1/2" X 112"). Circuits were otherwise identical, with respect to arterial filtration and cardioplegia delivery.

Group differences were calculated using the statistical package STATISTIX®. Student's t-test, one-tailed, was used for analysis of mean numerical differences and Chi-Squared for categorical data. P values less than 0.05 were considered significant.

RESULTS

Alterations to the bypass circuit resulted in a 800 ml decrease in priming volume. This represents approximately a 35 percent decrease in CPB circuit volume. Patients were well matched for age, BSA, sex, bypass time, ejection fraction, and procedure (Table 2). Significant differences were noted for patients' weights. Group LP had a significantly lower preoperative weight as compared to SP. A majority of the procedures were coronary artery bypass grafting (CABG). Remaining procedures included isolated valve replacements.

Throughout CPB several physiologic and metabolic parameters were similar in both groups (Table 3). The mean lowest core temp was 31°C in both groups. Oxygen delivery at the lowest hematocrit was similar in both groups.

As shown in Table 4, group LP patients had improved hematocrit status and required fewer homologous PRBC exposures than did group SP both during and post CPB. During CPB a sig-

<table>
<thead>
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<th>Variable</th>
<th>Low Prime n=40</th>
<th>Standard n=40</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest arterial O&lt;sub&gt;2&lt;/sub&gt; content (ml)</td>
<td>90.9 (14.7)</td>
<td>90.0 (14.1)</td>
<td>NS</td>
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<tr>
<td>O&lt;sub&gt;2&lt;/sub&gt; Delivery Index (ml O&lt;sub&gt;2&lt;/sub&gt;/min/m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>215 (60.2)</td>
<td>214 (47.3)</td>
<td>NS</td>
</tr>
<tr>
<td>Lowest Core Temperature (Celsius)</td>
<td>31 (1.5)</td>
<td>31 (1.6)</td>
<td>NS</td>
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<tr>
<td>Blood Flow Index at Lowest Hematocrit (l/min/m&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>2.4 (0.5)</td>
<td>2.4 (0.4)</td>
<td>NS</td>
</tr>
<tr>
<td>Rewarm Time (min)</td>
<td>25.8 (7.1)</td>
<td>27.0 (7.2)</td>
<td>NS</td>
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<table>
<thead>
<tr>
<th>Variable</th>
<th>Low Prime n=40</th>
<th>Standard n=40</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre CPB HCT %</td>
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<td>34.2 (4.3)</td>
<td>NS</td>
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<td>Initial HCT on CPB %</td>
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<td>18.4 (3.3)</td>
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<td>Number of Patients with CPB HCT &gt; 20%</td>
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<td>13/40</td>
<td>&lt;0.05</td>
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<tr>
<td>Number of Patients Transfused PRBC on CPB</td>
<td>9/40</td>
<td>18/40</td>
<td>&lt;0.04</td>
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<tr>
<td>Units of PRBC on CPB</td>
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<td>0.9 (1.2)</td>
<td>&lt;0.03</td>
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<tr>
<td>Immediate Post CPB HCT (%)</td>
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<td>19.3</td>
<td>0.08</td>
</tr>
<tr>
<td>Number of Patients Transfused During Hospital Stay</td>
<td>26/40</td>
<td>34/40</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>Units PRBC During Hospital Stay</td>
<td>1.9</td>
<td>2.4</td>
<td>NS</td>
</tr>
<tr>
<td>Discharge Hematocrit (%)</td>
<td>30.2 (2.9)</td>
<td>31.3 (3.3)</td>
<td>NS</td>
</tr>
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</table>
significantly higher percentage of group LP patients had hematocrits greater than 20%. Twice as many SP patients required homologous PRBCs during CPB. Lastly, the mean PRBC units transfused was lower in group LP. Immediately post CPB group LP hematocrits tended to be higher.

During the entire length of stay significantly fewer group LP patients required any homologous PRBC transfusions. There was a trend in group LP to receive fewer PRBC units throughout the hospital stay. As shown in Table 5, fluid balance, 24 hour chest tube drainage and 24 hour weight gain were similar for the groups.

Outcome results are shown in Table 6. There were no deaths in either group, length of hospital stays were similar, and complications rates were statistically identical.

**DISCUSSION**

Blood conservation requires a multi-modality program. To be successful it requires significant input from all disciplines involved with the cardiac patient. With the goal of bloodless surgery, this interdependence has led the perfusion team to develop pump-oxygenator circuitry which reduces hemodilution. Although hemodilution has been proven to be beneficial in terms of tissue perfusion and blood conservation, small and/or anemic patients experience a “hyperdilution” and require increased homologous transfusions (9).

In our comparison of the higher prime Cobe Excel to the lower prime Cobe Optima and Terumo Capiox SX, we identified several advantages in reducing prime volume. At the minimum operating levels, the lower prime oxygenators required approximately 600 ml less than the larger Cobe Excel. Use of a smaller venous line further reduced our total circuit prime by 200 ml, for a total decrease of 800 ml. An advantage of the Terumo SX over both Cobe units was the larger volume of the venous reservoir, 4500 ml versus 3600 ml. This feature is beneficial when faced with patients with an increased blood volume. It reduces the need to add an additional cardiomyom reservoir or other technique for the storage of blood volume. To handle excessive blood volumes some perfusionists hemoconcentrate with either a hemofilter or cell scavenger system. Our experience with this technique is that the plasma volume that is removed is frequently needed to restore the patient blood volume when terminating cardiopulmonary bypass.

When using an “open-reservoir” CPB circuit, low prime can increase patient safety and reduce homologous transfusion requirements. Reduction of the bypass circuit volume via low prime components allows the perfusionist to maintain a higher volume in the venous reservoir during cardiopulmonary bypass. With standard high volume circuitry, the perfusionist is occasionally challenged with operating the heart-lung machine at low venous reservoir levels and low flow rates to reduce hemodilution and anemia. Problems associated with this technique, however, include increased risk of air embolism and organ ischemia. Low prime can reduce the risk of air embolism by increasing the venous reservoir level.

By increasing the safety margin the perfusionist is afforded an increased reaction time in the event of a sudden decrease in venous return. Some authors recommend that the reservoir operating level be maintained at a minimum of 25% of the arterial blood flow (10). This is a requirement for bubble oxygenation systems, but appears excessive for newer membrane systems. When operated at the manufacturer’s recommended level, there is little chance of massive air embolism with membrane systems, especially when a centrifugal pump is used. Additional protection can also be provided with the use of an arterial filter, level sensor, and a bubble detector.

The small adult patient is at high risk of homologous transfusion when undergoing CPB. As part of a multi-modality approach to blood conservation low prime perfusion represents one of several options that can be taken. Other options include: autologous donation, erythropoietin, limitation of sampling for laboratory testing, aprotinin, intraoperative autologous donation, and reduced transfusion triggers (11, 12).

A method to reduce homologous blood transfusion has been described. Low prime perfusion is simple, safe and cost effective. In adult patients with low estimated blood volume, this tech-
nique affords the cardiac team another tool in the effort for bloodless surgery.

REFERENCES