Hematocrit and Blood Volume Control during Cardiopulmonary Bypass with the Use of Hemofiltration

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Control of plasma water volume, whether in the patient with renal failure, congestive heart failure, shock with pulmonary edema, or during cardiopulmonary (C-P) bypass, can be achieved by the use of hemofiltration. This is a process that imitates physiologic glomerular filtration by applying a hydrostatic pressure gradient across a porous membrane. This causes convective mass transport of water and molecules up to a molecular weight determined by the membrane pore size (20,000 to 60,000 daltons for membranes in current use). Ultrafiltrate flux rates are determined by the properties of the membrane itself and by blood flow, transmembrane pressure gradient, hematocrit, and plasma protein concentration.1,2 In the hemofilter, blood flows through parallel asymmetric hollow fibers made of the membrane being used. The membrane material and hollow fiber characteristics vary with different manufacturers.3

Though the concept of hemofiltration was developed for use in the patient with renal failure, it has a much wider application in clinical situations in which the intravascular volume of water is excessive.4–7 During C-P bypass, hemofiltration has been used for hemococoncentration, especially where excess extracorporeal volume occurs8,9 and is much more efficient than dialysis for this purpose. Specifically, hemofiltration can be used during C-P bypass in the anuric patient and Case 1 below describes such a use not previously reported. The second case below extends the clinical use of the hemofilter to a situation where excess hemodilution in the presence of an expanded circulating blood volume can be anticipated. Normally, during and after C-P bypass, hemococoncentration is achieved largely by the production of a diuresis and any situation where this mechanism may not be achieved, or may be overwhelmed, is a potential indication for hemofiltration.

REPORT OF TWO CASES

Case 1. A 42-year-old woman with analgesic nephropathy and anuric renal failure, receiving regular ambulatory peritoneal dialysis, was admitted with peritonitis and marked congestive cardiac failure. Cardiac catheterization revealed pulmonary hypertension (pulmonary artery pressure 100/44 mmHg) and mildly impaired left ventricular contractility as well as mitral valve stenosis and aortic valve incompetence. There was significant disease of the LAD coronary artery.

Her peritonitis improved rapidly after she received antibiotics, and she was changed to hemodialysis for more versatile fluid and electrolyte management. She was transfused with two units of packed erythrocytes, which increased her preoperative hematocrit from 25% to 37%. For 3 days preoperatively, she was hemodialized daily to reduce her total body potassium and to control intravascular fluid volumes during blood transfusion.

The patient weighed 38 kg, with a body surface area 1.4 m², and extracorporeal circuit priming was achieved with 1,400 ml of lactated Ringer’s solution and two units of packed erythrocytes. A Bentley BOS-105 oxygenator was used, and a Gambro blood concentrator 202 was added to our routine circuit as shown in figure 1.

The total C-P bypass time was 84 min, with 68 min of aortic cross-clamping. Cardioplegic arrest was achieved by instillation of a total of 1,100 ml of St. Thomas cardioplegic solution directly into the coronary ostia at 20–30-min intervals. The hemofilter was used intermittently during C-P bypass, as indicated by high oxygenator volumes and serial hematocrits of circulating blood. On these occasions the parallel circuit was activated using a roller pump (fig. 1) to maintain transmembrane pressure of 200–250 mmHg, and approximately 100 ml·min⁻¹ of filtrate was obtained. A total of 850 ml of plasma water was removed, and serum electrolytes and hematocrits are shown in table 1.

The patient returned to the intensive care ward, receiving iv infusions of dobutamine, 5 μg·kg⁻¹·min⁻¹, and of sodium nitroprusside, 1.0 μg·kg⁻¹·min⁻¹, but was otherwise stable. However, she lost 1,400 ml blood in ½ hours and returned to the operating room, where bleeding from a sternal wire site was identified and controlled. One hour after returning to the ward, peritoneal dialysis was commenced, and her progress was uneventful. Her endotracheal tube was removed the morning after surgery, and the dobutamine infusion was ceased 72 h postoperatively.

After a long hospital convalescence, the patient was discharged on the 99th postoperative day to continue home peritoneal dialysis.

Case 2. A 48-year-old woman with rheumatic aortic and mitral valve disease had previous replacement of both of these valves. On this admission she had congestive cardiac failure aggravated by incompetence of the prosthetic mitral valve and by gross tricuspid incompetence. She was hyponatremic and had an excessive intravascular volume with distended pulsatile veins and hepatosplenomegaly. Cardiac

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catheterization showed the pulmonary vascular resistance to be normal and left ventricular contraction to be moderately impaired, associated with moderate mitral incompetence (grade 3 in a range of 1–4). Surgery was scheduled for aortic and mitral valve replacement and tricuspid annuloplasty.

The patient weighed 60 kg with a body surface area 1.65 m², and the preoperative hematocrit was 30%. The extracorporeal circuit (fig. 1) was primed with 2 l lactated Ringer's solution and 100 ml 25% albumin. During the bypass time, 1,200 ml of aequous St. Thomas cardioplegic solution was administered in three doses, and two units of packed erythrocytes were added to the circuit. The total bypass time was 153 min, including a 93-min aortic cross-clamp time. The hemofilter was used on three occasions as described previously, with 200–250 mmHg of transmembrane pressure and a total of 1,000 ml ultrafiltrate removed. After the first dose of cardioplegic solution, hemofiltration was used to bring the hematocrit up to the middle 20% range. After 100 min of bypass time, the hemofilter was used again to reduce total circulating blood volume and allow packed erythrocyte transfusion. Toward the end of the bypass time, hemofiltration was commenced again for hematocrit and serum electrolyte values are shown in table 2.

The postoperative course was complicated by low-output cardiac failure, with a need for iv catecholamine infusions, and by prerenal, renal failure and prolonged ventilator dependence.

**Table 1. Case 1. Electrolyte and Hematocrit Results**

<table>
<thead>
<tr>
<th></th>
<th>Na⁺ (mEq·L⁻¹)</th>
<th>K⁺ (mEq·L⁻¹)</th>
<th>HCT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prebypass</td>
<td>134</td>
<td>5.3</td>
<td>37</td>
</tr>
<tr>
<td>10 min on bypass</td>
<td>136</td>
<td>5.1</td>
<td>29</td>
</tr>
<tr>
<td>2 h on bypass</td>
<td>135</td>
<td>5.9</td>
<td>28</td>
</tr>
<tr>
<td>Postbypass</td>
<td>136</td>
<td>5.7</td>
<td>33</td>
</tr>
</tbody>
</table>

She eventually was discharged on the 35th postoperative day to her home.

**DISCUSSION**

The decision to offer cardiac surgery to a functionally anephric patient receiving maintenance dialysis is based on the prospect for a good outcome and improved quality of life. The social and economic considerations in such cases have been debated¹⁰,¹¹ and the physician's obligation to the individual patient emphasized.

Hemofiltration is an efficient way to remove plasma water and components (in proportion to their plasma concentrations) and to reduce circulating blood volume. Without altering serum electrolyte concentrations or acid base status, ultrafiltrate volumes of greater than 100 ml·min⁻¹ of plasma water can be removed to achieve hemoconcentration (fig. 2). Hemodialysis, on the other hand, is used to alter the concentration of serum components. This technique is inefficient for controlling circulating blood volume or hematocrit, since volumes only up to 10 ml·min⁻¹ can be removed. Although serum electrolytes can be adjusted using hemofiltration, it is beyond the scope of this report to discuss this.

Excess hemodilution is a problem in long bypass operations with repeated use of crystalloid cardioplegic solution, particularly where a small adult is having complex surgery. Removal of intravascular fluid by hemofiltration is a simple and safe method for achieving hemoconcentration and for reducing circulating blood volume using a closed-loop system during C-P bypass (fig. 1). The equipment used in the cases reported was a Gambro® blood concentrator 202, which is a hemofilter of asymmetric hollow fiber polyamide membrane. The effective membrane area is 1.2 m², with a 220-μm internal diameter and about 6,500 fibers 5 cm long, with a priming volume of 82 ml. The filtration rate is determined by hematocrit, protein concentration, blood flow, and transmembrane pressure across the filtration unit. The relationships between filtration rate and transmembrane pressure (at constant blood flow) or blood flow (at constant transmembrane pressure) are given by the manufacturers (fig. 2). Removal of solutes is determined by the pore size of the membrane, and substances of MW up to 20,000 dal-

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¹ Gambro Pty. Limited, Head Office, Box 10101, S-22010, Lund, Sweden.
tons are removed effectively by the Gambro fiber hemofilter.

The composition of the ultrafiltrate is similar to glomerular filtrate with concentrations of solutes the same as those of plasma water. Therefore, no change of plasma electrolyte concentrations or of acid-base status results, and potassium depletion, characteristic of postbypass diuresis, is modified. Protein loss has been measured as 1–2 g l⁻¹ of ultrafiltrate; the plasma oncotic pressure is thought to be unchanged or to rise; fibrinogen level remains unchanged; and plasma-free hemoglobin does not rise. Silverstein et al. have calculated maximum ultrafiltration flux rates for different blood flows and hematocrits to avoid excessive ultrafiltration and the possible risks of hyperviscosity. They have found that erythrocyte damage is very small with a maximal filtration rate of 20% of plasma water and is less than with convective tubing pumps used for hemodialysis. Transmembrane pressure should not exceed 500 mmHg, and the ultrafiltration rate is proportional to the blood flow rate at any given transmembrane pressure. In the cases presented, we used a nonocclusive roller pump at 300 ml·min⁻¹ flow and maintained a transmembrane pressure of about 250 mmHg to remove increments of 200–300 ml of filtrate during C-P bypass.

In each of the cases presented, plasma water was removed during C-P bypass. In Case 1, this was done to achieve hemococoncentration in a functionally anephric patient and in Case 2, this not only assisted hemococoncentration of circulating blood, but also reduced circulating blood volume to allow packed erythrocyte transfusion without producing excessive intravascular volumes. On each occasion we were faced with long bypass times and hemodilution by cardioplectic solution. Both patients were small women who faced a difficult postoperative course with compromised renal function. The Gambro fiber hemofilter is easy to use in conjunction with C-P bypass and has no side effects, though the manufacturers' operating instructions and recommendations must be followed rigidly to avoid damage to the blood.

Heparin has a molecular weight of less than 20,000 and therefore will be removed in the filtrate. Therefore, anticoagulation should be monitored closely, using the activated clotting time when hemofiltration is used during C-P bypass and heparin added as indicated.

In this report we defined the indications for the use of hemofiltration during C-P bypass and to emphasize its simplicity of application. We recommend its use in patients with renal failure and in patients with cardiac failure, in whom prolonged bypass (greater than 1 h) is anticipated. The objectives in using this technique are to hemococoncentrate the circulating blood and to reduce circulating volume during C-P bypass. These controls can be achieved simply and without serum electrolyte change, loss of serum proteins, or hemolysis; however, the coagulation status must be monitored closely.

REFERENCES