Ultrafiltration in Cardiac Surgery

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Abstract

Cardiopulmonary bypass (CPB) may result in hemodilution and volume overload. Restoration of a normal hematocrit is important for post-operative myocardial performance. Diuretics, conventionally used in the post-operative period may be ineffective due to renal impairment or lead to electrolyte imbalance.

Hollow-fiber hemofilters, made of an anisotropic polysulfone membrane (AMICON Diafilter) have been used for the ultrafiltration of blood in cardiac surgery during CPB. The hemofilter is inserted in the arterial line of the CPB. With this method ultrafiltration of the priming volume and restoration of the pre-operative hematocrit can be achieved and edema can be reversed.

In our experiments, performed in dogs ($n = 5$) we removed 1 L of an ultrafiltrate of plasma water in 15 minutes without hemodynamic changes or electrolyte imbalance. In the same time hematocrit increased from 19 to 29% ($p < 0.05$) and protein concentration from 2.7 to 5.4 g/dl ($p < 0.05$). Simultaneous studies with Cr-labelled RBC's demonstrated that blood volume was not significantly altered from pre CPB values during ultrafiltration, suggesting that the origin of the removed ultrafiltrate was mainly from the extravascular space.

In conclusion, the insertion of a hemofilter in the CPB either during or at the end of bypass allows the removal of the priming volume and prevents post-operative hemodilution and fluid overload without compromising hemodynamic stability. The use of hemofilters in cardiac surgery is safe and indicated for patients with CHF, fluid overload, renal impairment and long bypass time. In addition, the hemoconcentration achieved with the hemofilters may reduce transfusion requirements and improve myocardial performance.

Introduction

The extracorporeal circuit in cardiopulmonary bypass (CPB) requires that the circulating blood volume of the patient is expanded by up to 2 liters or more. While in earlier years the extracorporeal circuit (ECC) was primed with whole blood or blood products it has become practice in recent years to use crystalloid solutions for this purpose. As a consequence the patient's blood is diluted by the priming volume causing a fall of hematocrit and protein concentration of up to 50%. Due to the decreased oncotic pressure part of this volume is redistributed during the intra-operative period to the extravascular space resulting in fluid overload and edema.[1,2]

Conventionally at the end of surgery the entire or part of the volume of the ECC is returned to the patient, who is frequently left with a low hematocrit and the fluid overload. Both the lowered hematocrit and the fluid overload represent a burden for the post-operative myocardial performance.[3] To prevent this complication either the priming volume including the red blood cells (RBC's) is discarded or the RBC's from the left-over blood (in the oxygenator) are separated by centrifugation or filtration and then returned to the

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patient.[4,5] Both these approaches involve only the oxygenator blood of the CPB while the patient remains with a low hematocrit and fluid overload.

A simple method to reverse the detrimental effects of hemodilution is intra-operative ultrafiltration. In recent years hemofilters with high ultrafiltration characteristics have become available and are used as an alternative to hemodialysis in the end stage renal disease.[6] A hollow fiber filter made of an anisotropic polysulfone membrane (Amicon-Diafilter-30)[a] was inserted in the ECC. This filter is made of 6000 fibers of 25 cm length with a surface area of 0.6 m^2. With an internal diameter of 0.2 mm, a pore size of only 1000 Å and a molecular cut-off rate of maximally 50,000 Daltons, the filter prevents the loss of proteins. The insertion of such a hollow fiber filter in the ECC allows removal of an ultrafiltrate of plasma water close to the CPB priming volume without hemodynamic changes,[7] and the effects of hemodilution can be reversed with preservation of RBC's.[8]

Method

Five anesthetized mongrel dogs were subjected to one hour of normothermic CPB after thoracotomy and full heparinization using two venous and one arterial cannulae and an adult size bubble oxygenator (Bellco)[b]. The animals' average weight was 23 kg. Two liters of Ringer's lactate solution served as priming volume, reducing the hematocrit to below 20%. After one hour of total CPB, partial bypass was continued and an Amicon-30-hollow fiber-filter was incorporated in a parallel post-pump circuit to the arterial line (Fig. 1). One liter of ultrafiltrate was removed in each animal and discarded. Two-hundred-fifty ml of oxygenator blood were not given back to the animals and discarded with the system. The transmembrane pressure was kept below 500 mmHg by adjusting the blood flow which varied according to the hematocrit between 533 and 300 ml/min (QB), yielding a maximal filtration flow (QF) of 75 ml/min. The following parameters were studied at the beginning and at the end of filtration: filtration rate and volume, blood flow (Biotronics)[c] and pressure, hematocrit, electrolytes, cell count of blood and filtrate.

In addition, blood volume measurements were performed by the technique of chromium labelled Erythrocytes (Cr* RBC)[9]. Electrocardiogram and hemodynamic parameters were continuously recorded on a (Brush Gould System 2000)[d] eight-channel recorder. This included central venous pressure, pulmonary artery pressure (Swan-Ganz 7F catheter)[e], aortic pressure and left ventricular pressure (dip tip Milar 5F catheter)[f] and its first derivative dP/dt, a parameter of isovolumic contractility. To assess myocardial edema, transmural left ventricular biopsies were taken before and after filtration. The water content was measured by the wet and dry weight method.[10] Data are expressed as mean ± standard deviation (SD), statistical significance was obtained by the Student's T-test.

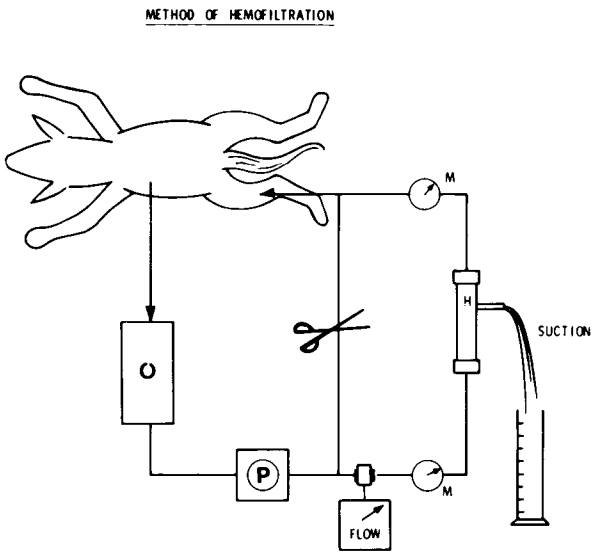

FIGURE 1. Experimental Protocol
O = Oxygenator
P = Roller pump
M = Manometer
H = Hemofilter
Flow = Blood flow

Results

Before the end of CPB 1 liter of ultrafiltrate was removed from each dog in a mean time of 16 minutes. The mean values of pressures and flow rates during filtration are summarized in Figure 2. However, blood flow (QB) and filtration rate (QF) varied with the hematocrit: at the beginning of the

[a]Amicon Corporation, Danvers, MA 01923
[b]BELLCO (Oxibel D600), Dideco, s.p.a. Mirandola I-41037 Italy
[c]Biotronics 3/S Extracorporeal, Silver Spring, MD
[d]Brush-Gould, Inc. Cleveland, OH 44114
[e]Edwards Laboratories, Inc. Santa Ana, CA 92711
[f]Milar Instruments, Inc. Houston, TX 77223

procedure with a hematocrit of 19%, blood flow (QB) was 533 ml/min and filtration rate (QF) 75 ml/min. With a hematocrit of 29% at the end of filtration QB was 300 ml/min and QF 54 ml/min.

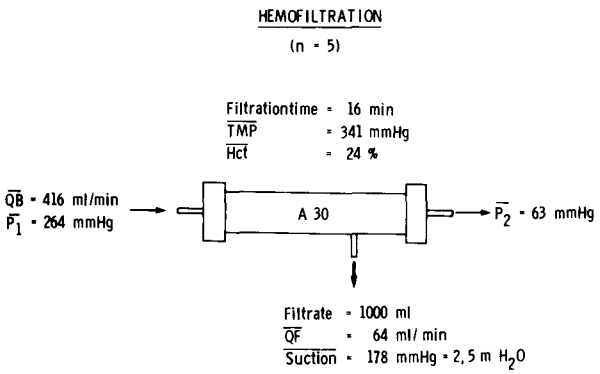

FIGURE 2. Pressures and Flow Rates During Ultrafiltration
TMP = Transmembrane pressure
Hct = Hematocrit
QB = Blood flow
QF = Filtration rate
P_1/P_2 = Pre and post filter pressure

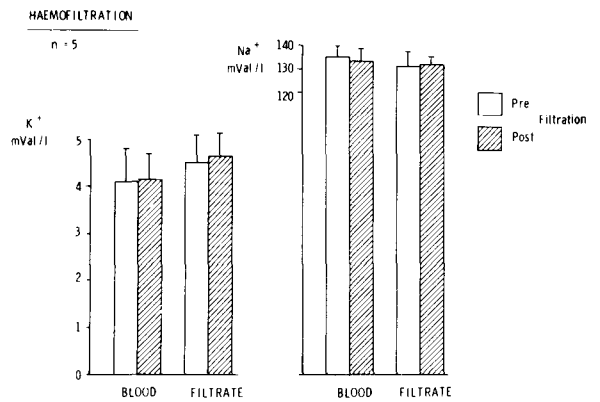

FIGURE 3. Electrolyte Concentration in Plasma and Filtrate at the Beginning and End of Filtration (mean ± SD)
Na^+: Sodium (mEq/l)
K^+: Potassium (mEq/l)

Electrolyte concentration, pH, blood urea nitrogen and creatinine were similar in the plasma and the ultrafiltrate at the beginning and at the end of filtration (Figure 3). Osmolality before bypass was 290, after total bypass 284 and after filtration 296 mOsm/kg. These changes are not significant and remain within the normal range.

No protein or hemoglobin was found in the filtrate. As a result of the removal of ultrafiltrate the protein concentration in plasma doubled from 2.7 to 5.4 g/dl ($p < 0.05$). Hematocrit decreased from a pre CPB value of 40% to 19% ($p < 0.001$) immediately after hemodilution at the beginning of CPB and increased to 29% ($p < 0.05$) after ultrafiltration of 1 liter.

Plasma hemoglobin, as an indicator of hemolysis, was in the range of 48 mg/dl (baseline in our laboratory: 0.5 ± 0.3). This is comparable to an expected degree of hemolysis after one hour of CPB in dogs without hemofiltration in our laboratory.

Blood volume measured with chromium labelled RBC's showed an increase from 1.6 to 2.1 liters ($p < 0.05$) from pre-CPB to the beginning of filtration and a decrease to 1.9 liter at the end of filtration (n.s.).

The hemodynamic parameters remained stable throughout the experiment. No significant changes in heart rate or pressures were found in any dog during filtration of 1 liter. There was a moderate increase in left ventricular contractility parameters in four out of five dogs (max dP/dt 2436 ± 367 pre-CPB; 1806 ± 211 post-CPB and 1950 ± 176 mm Hg/sec. post-filtration). The myocardial water content was 78% on CPB before filtration and decreased to 74% after filtration (n.s.). Even during rapid hemofiltration when 1 liter of filtrate was removed within 6 minutes (Amicon 40) no major hemodynamic changes occurred. The slight depression of various pressures at the end of filtration corresponds to the simultaneous end of partial cardiopulmonary bypass (QB = 600 ml/min).

Discussion

The ECC in CPB requires a priming volume of several liters. Crystalloid solutions are used widely for this purpose mainly to save blood and to improve blood viscosity.[2,11] This hemodilution leads to fluid overload and decreased oxygen carrying capacity and may impair post-operative myocardial performance.[3]

In a majority of cases these effects are reversed with the use of diuretics in a reasonable time. Hemodilution and fluid overload can persist in patients with pre-existing CHF, impaired renal function and as a result of a long, complicated period on the CPB.[12] In addition, excessive use of diuretics may induce electrolyte imbalance and hemodynamic instability.

Discarding the leftover volume of the CPB or centrifugation or isolated filtration of the oxy-

genator blood has been used to minimize the adverse effects of hemodilution.[4,5] The disadvantage of these methods is that in the former the patient is left with a low hematocrit and in the latter, while the hematocrit is moderately increased, the unaltered low protein concentration prevents the reversal of the extravascular volume overload.

Ongoing ultrafiltration during or at the end of surgery while the patient is still connected to the CPB is a simple and effective method for reversal of hemodilution. With this method RBC's can be preserved, the hematocrit progressively increased and the transfusion requirements decreased. Hemodilution with crystalloid solutions results also in a decrease of plasma protein concentration at the onset of the CPB. This facilitates fluid shift from the intravascular to the extravascular space by the mechanism of decreased oncotic pressure. In addition, capillary permeability is increased after long periods on the CPB.[2] Severe fluid overload and edema leading to multi-organ failure is a frequent complication of CPB.

Discarding of the prime volume or concentration by centrifugation or filtration are inappropriate measures to reverse this complication. Ultrafiltration with a filter impermeable to protein increases the plasma protein concentration progressively, while an ultrafiltrate of plasma water is removed. The increase of blood oncotic pressure facilitates shifts back from the extravascular to the intravascular space and thus maintains blood volume while the effects of the hemodilution are reversed.

Hemodynamic stability was observed in our experiments (Fig. 4), despite the removal of one liter of ultrafiltrate. This represents 50% of the calculated intravascular volume of these animals. The stability of the blood volume during this ultrafiltration period implies that most of the ultrafiltered fluid must have originated in the extravascular space. This was confirmed by Magilligan, et al., who demonstrated a significant decrease of lung water content using this method.[13]

In conclusion, the insertion of a hemofilter in the CPB either during or at the end of bypass allows the removal of the priming volume and prevents postoperative hemodilution and fluid overload without compromising hemodynamic stability. The use of hemofilters in cardiac surgery is safe and indicated for patients with CHF, fluid overload, renal impairment and long bypass time. Moreover the hemoconcentration achieved with the hemofilters may reduce transfusion requirements and improve myocardial performance.

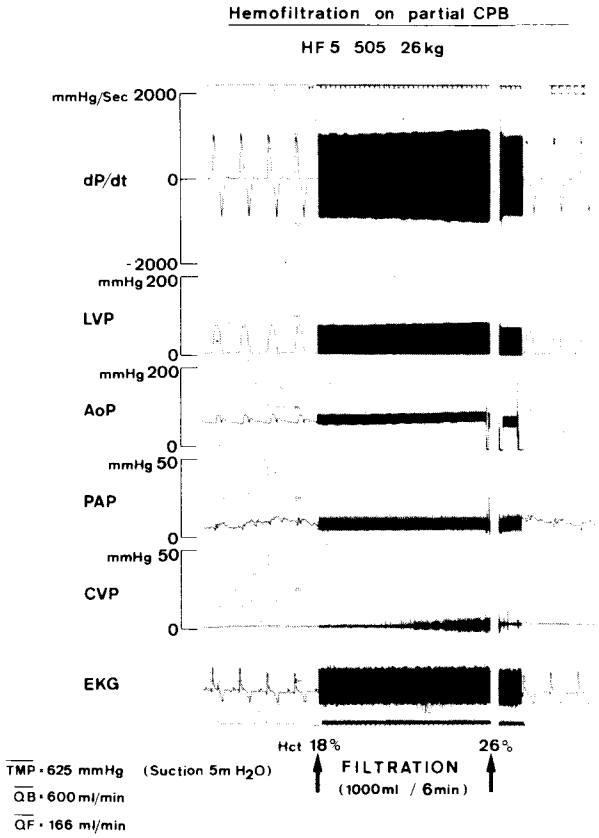

FIGURE 4. Hemodynamic Changes During Rapid Ultrafiltration on Partial CPB (1 liter within 6 minutes)

dP/dt = Parameter of isovolumic contractility
LVP = Left ventricular pressure
AoP = Aortic pressure
PAP = Pulmonary artery pressure
CVP = Central venous pressure
TMP = Transmembrane pressure
QB = Blood flow
QF = Filtration rate

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