To Wash or Not To Wash: Controlling Sodium, Glucose and Osmolarity In A Pediatric Extracorporeal Circuit Blood Prime

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Disclaimer

This article summarizes the methods and results of two decades of washing blood primes for extracorporeal circuits at The Children's Mercy Hospitals and Clinics in Kansas City, Missouri, USA. While the methods described herein are successful at our hospital, there is no assurance that they will provide the same results at another program.

Introduction

The cardiopulmonary bypass (CPB) circuits used in infant heart surgery have significantly less volume than adult circuits. However, the ratio between a patient's blood volume and the circuit volume is quite different. The typical adult CPB circuit holds about 1500 mls with a 300 mls reservoir volume compared to a blood volume of approximately 4800 mls in an 80kg adult; a relationship of 0.31/1. The blood volume of a 3 kg infant is approximately 300 mls while the typical infant CPB circuit with cardioplegia and hemoconcentrator apparatus might be about 700 mls including a 150 mls venous reservoir volume; a relation ship of 2.3/1. Therefore, the composition of the CPB circuit prime can have an impact on the patient's homeostasis.

Crystalloid priming of an infant CPB circuit is not practical and would cause a severe reduction in hematocrit and coagulation factors. Therefore, these circuits are often primed with packed red blood cells along with fresh frozen plasma to help maintain adequate levels of hemoglobin, fibrinogen and other coagulation factors. Preserved blood products contain levels of electrolytes and glucose that exceed accepted normal values that would be considered lethal if measured directly from a patient's own blood[1, 2]. Upon the initiation of CPB, the infant experiences a massive and sudden whole body transfusion of this preserved blood that can dramatically affect electrolyte and glucose concentrations.[3]

In an effort to avoid this unnecessary complication of infant CPB many pediatric perfusionists 'wash' the blood products used in the priming of the circuit. Our program has been washing the CPB prime to reduce the glucose concentration since the late 1980's. Our sternal infection rate has been approximately 0.02% over the decades, in part we believe, due to the removal of excess glucose from the pump prime. From a survey by the Maine Medical Center, 35% of pediatric programs use washed packed red blood cells

(PRBC)[4]. An unknown number of programs perform some form of pre-CPB hemoconcentration wash on the circuit prime [2, 4-11]. In the author's opinion, however, the most important aspect is to select a wash method that reduces the glucose concentration and maintains a normal sodium and bicarbonate level.

Pediatric open heart surgery and ECMO treatment are associated with numerous complications. Whether any of these are caused directly by a hypernatremic and/or hyperglycemic blood prime is uncertain. What is certain is that hypernatremia and hyperglycemia are definitely implicated in many complications in patients, young and old, not necessarily on extracorporeal support[12-23].

The decision to begin blood prime washing in a pediatric heart surgery program or ECMO program should be based on past outcomes. Do your blood primes have some degree of hypernatremia and/or hyperglycemia and is the frequency of edema, renal failure, infection and neurologic sequelae in your program acceptable and comparable to other programs? If your outcomes are worse, then consideration should be given to washing the blood prime in future cases. If your program is not keeping track of outcomes, it should begin to do so before making any changes.

At The children's Mercy Hospitals and Clinics, Kansas City, Missouri, USA, two basic methods are used to wash blood primes; 1) hemodilution followed by hemoconcentration in CPB circuits and 2) hemodialysis of the circuit prime in ECMO circuits.

Hemodilution with Hemoconcentration of the CPB Circuit Prime

This method is most applicable when the extracorporeal circuit volume can handle large volume changes as a result of a venous reservoir, cardiotomy reservoir or venous bag. Because this method calls for priming the infant circuit with an excess of glucose free crystalloid solution, solutions containing calcium should be avoided for two reasons. Firstly, the presence of calcium in the solution may cause the preserved blood to clot. Secondly, if heparin is added to the crystalloid prevent the blood from clotting an unknown amount of heparin will be removed during the hemoconcentration phase leaving the prime blood with an indeterminate amount of heparin. Heparin does not need to be added if calcium free solutions are used until washing is complete and the pH and electrolytes are normalized.

If 500 mls of blood products are to be used, the glucose free crystalloid solution used for priming should be 3 times the blood product volume. This will dilute the glucose to an acceptable range. For example, if a unit of PRBC and a unit of fresh frozen plasma (FFP) are combined (total volume 500 mls), the glucose would be about 500 mg% (approximately 28 mmol/L). Combining this blood with 1500 mls of glucose free crystalloid results in a volume of 2000 mls and a glucose concentration of 125 mg% (6.9 mmol/L). The hematocrit, proteins and coagulation factors are diluted as well, but are returned to an acceptable value by hemoconcentrating the prime to an acceptable volume using a hemoconcentrator (the Asahi PAN 03, for example) to return the hematocrit, protein and coagulation factors to a higher level.

The difficulty with this technique is in returning the buffer base to normal levels without increasing the sodium (Na) to an abnormally high level. Na and its major anions, chloride (Cl) and bicarbonate (HCO3), are responsible for a major portion of the osmolarity of the blood. The osmolarity of blood can be estimated using this formula;

$$(\text{Na in mEq/L} \times 2) + (\text{glucose in mg\%} \div 18) + 15 = \text{osmolarity in mosmol/L}$$

The normal blood osmolarity is about 270-300 mosmols. When washing is completed using Plasma-Lyte 148 for example, the hemoconcentrated blood prime has a Na of 140 mEq/L and a glucose of 125 mg%. Using the formula above the osmolarity would be 302 mosmols/L before the buffer base is normalized. If the HCO3 level is 4 mEq/L and needs to be normalized to 24 mEq/L, 20 mEq/L of NaHCO3 would need to be added. Since the circuit holds 700 mls, the amount of NaHCO3 would only need to be 14 mEq. However, the effect would be to increase the Na to 160 mEq/L and the osmolarity to 342 mosmol/L.

The NaHCO3 must be added to the prime because the glucose free crystalloid usually contains more stable anions like acetate or gluconate. These anions cannot function as buffers in the normal pH range of blood and must be converted to HCO3 in the adult liver. However, infants cannot metabolize these molecules as readily into HCO3. Adding NaHCO3 to the blood or the crystalloid during hemodilution or after hemoconcentration will help to normalize the HCO3. But, the Na and osmolarity will still be elevated above normal limits. The post-CPB consequences can be impaired renal function, edema and occult brain damage. However, without hemodilution and hemoconcentration the glucose would be about 500 mg% instead of 125 mg% and the same amount of NaHCO3 would need to be added, making the osmolarity approximately 363.

The problem of excessive Na concentration due to the addition of NaHCO3 to the blood can be alleviated by modifying the glucose free crystalloid solution. For example, Plasma-Lyte 148 has the following electrolyte composition:

Sodium	140 mEq/L
Potassium	5 mEq/L
Calcium	0 mEq/L
Magnesium	3 mEq/L
Chloride	98 mEq/L
Acetate	27 mEq/L
Gluconate	23 mEq/L
Osmolarity	294 mosmol/L

If the HCO3 level is normalized by the addition of 24 mEq of NaHCO3 the composition would be as follows:

Sodium	164 mEq/L
Potassium	5 mEq/L
Calcium	0 mEq/L
Magnesium	3 mEq/L
Chloride	98 mEq/L
Acetate	27 mEq/L
Gluconate	23 mEq/L
Bicarbonate	24 mEq/L
Osmolarity	342 mosmol/L

A modified crystalloid wash solution can be mixed when a liter bag of Plasma-Lyte 148 (1050 mls including overfill) is combined with 400 mls of sterile water and 50 mEq of NaHCO3 (1 mEq/ml), the resulting washing solution has a volume of 1500 mls with the following electrolyte composition:

Sodium	127 mEq/L
Potassium	3 mEq/L
Calcium	0 mEq/L
Magnesium	2 mEq/L
Chloride	65 mEq/L
Acetate	18 mEq/L
Gluconate	15 mEq/L
Bicarbonate	33 mEq/L
Osmolarity	264 mosmol/L

The osmolarity of this solution is slightly below normal (270-300 mosmol/L). If this modified crystalloid wash solution is used, adding the FFP first to the circuit followed by the PRBC prevents any hemolysis due to a low osmolarity. FFP has a Na concentration of 172 mEq/L and a glucose concentration of 535 mg% (29.7 mmol/L) resulting in an osmolarity of approximately 389 mosm/L[1]. The modified wash solution (1500 mls) and FFP + PRBC (500 mls) conglomeration can be hemoconcentrated to the desired volume and requires less pH adjustment with additional NaHCO3. The excess CO2 generated by consumption of the HCO3 in the acidotic blood can be adjusted using the sweep gas flow.

The numbers used in the above examples are idealized. In reality, the actual results are different, probably due to the variable nature of electrolyte concentration in various blood products. In our own experience using unmodified glucose free crystalloid wash solution, 1 unit of PRBC and 1 unit of FFP, the resultant average Na of the prime blood is 176 mEq/L, the glucose 220 mg% (12.2 mmol/L) and the osmolarity 369 mosmol/L following the addition of enough NaHCO3 after washing to normalize the HCO3 level. Using the modified glucose free crystalloid wash solution, the average Na of the prime blood is 148 mEq/L, the glucose 229 mg% (12.7 mmol/L) and the osmolarity 313 mosmol/L. Patients receiving the modified glucose free crystalloid wash solution have better renal function and less edema during post-operative recovery, based on our own observations.

Hemodialysis of the ECMO Circuit Prime.

We had not washed the ECMO circuit blood since beginning our ECMO program in 1987 due to the perceived technical difficulty. The average Na was 167 mEq/L, the glucose 594 mg% (33 mmol/L) and the osmolarity 381 mosmol/L of this unwashed prime blood. Beginning in 2006, having solved the technical problems, we began washing the ECMO prime blood for the first time. The average Na was 130 mEq/L, the glucose 216 mg% (12 mmol/L) and the osmolarity 287 mosmol/L of this washed prime blood. Like the CPB patients, renal function and edema is improved in ECMO patients receiving washed blood primes.

The hemodialysis method is used when the extracorporeal circuit volume is fixed, like a closed ECMO circuit. A small hemodialyzer (Baxter CA-50, 0.5 M^2) is used with short blood lines that attach to luer adapted connectors in the main ECMO circuit. Additional tubing is attached to each dialysate port that is long enough to reach above the highest level of the ECMO circuit. At the end of each of these dialysate port tubes a flexible 2L bag is attached and the dialysate port tubing clamped. In one of the bags the modified wash crystalloid is placed (wash bag). The other bag is left empty (catch bag). The wash bag should be hung 3-4 inches higher on the IV pole than the catch bag. After the ECMO circuit is primed with blood and recirculating, the blood flow is diverted through the hemodialyzer. As before, the modified wash solution should be about 3 times the blood product volume. Both of the flexible bags should be kept higher than the ECMO circuit tubing, with the wash bag about 4 inches higher than the catch bag. This will prevent the removal of some of the circuit volume by ultrafiltration through the hemodialyzer during washing. Before washing begins, NaHCO3 is added to the blood. Our ECMO circuit holds 600 mls of blood products and we add 12 mEq of NaHCO3 just prior to washing. With the blood recirculating though the circuit and the hemodialyzer at approximately 200-300 mls/min the wash bag and catch bag tubes are unclamped. Wash solution flows from the wash bag through the hemodialyzer and into the catch bag at a speed of 200-300 mls/min. Once the wash bag is empty and the catch bag full, the flow can be reversed if additional glucose removal is required. Multiple passes can be made if needed to adjust the HCO3 and glucose levels.

Even though the two wash methods use the same modified wash solution, the resultant Na concentrations are different. In our experience, the CPB prime Na averages 148 mEq/L and the ECMO prime Na averages 130 mEq/L. This is probably due to the fact that one method uses hemoconcentration and the other method uses hemodialysis. Even though the sieving coefficient of Na across the typical ultrafiltration membrane is 1, there still tends to be a slight concentrating effect on the blood side for Na that is not seen when dialysis is used as the transport mechanism for glucose removal.

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