Ultrafiltration in Pediatric Cardiac Surgical Procedures

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Abstract

Ultrafiltration is an extracorporeal technique that employs the principle of convective solution transport across a semipermeable membrane and by which plasma water is removed from the dilute blood during cardiopulmonary bypass. Ultrafiltration has been used in 40 pediatric cases who underwent corrective surgery for congenital heart disease (TOF 12, VSD 23, ASD 4 and PAVC 1) intraoperatively. The patients' ages ranged from 10 months to 9 years (4.9±2.6 yrs) and weights from 7 to 28 kgs (16.4±5.8 kgs). The ultrafiltrator was interposed in the port of arterial filter of the CPB circuit and performed during the rewarming period. Ultrafiltration blood flow rate was 250-300 ml/min and negative pressure was less than -250 mmHg. The average ultrafiltrability (total blood flow volume/ultrafiltration fluid volume) was 11.2% (10.7-12.1%). After ultrafiltration HCT increased from 16.1% (15-18%) to 34.7% (32-40%). In the ICU, 5 cases (TOF 3, VSD 1 and ASD 1) had hemoglobinuria.

The indications of ultrafiltration in pediatric cardiac surgery are: 1. The initial perfusion is conducted with bloodless priming or with blood priming when the HCT value dropped to lower than 17% during CPB. 2. The CPB time is longer than 2 hours. 3. The patient receives digoxin and diuretics preoperatively or has complex anomalies.

Our experience showed that ultrafiltration during pediatric CPB is facile, safe, and effective. It may result in a reduced amount of fluid accumulation in extracellular fluid space with hemodilution perfusion which benefits the patient's postoperative recovery.

Hemoconcentration of dilute blood during cardiopulmonary bypass (CPB) by plasma water removal is an extracorporeal technique (ECB) by ultrafiltration during the pediatric open-heart surgery. Usually after CPB, especially in infant cases, the residual pump blood volume is much more than the acceptable volume for postoperative transfusion. Therefore, the transfusing of large volumes of dilute blood with low colloid oncotic pressure to the patient may cause circulatory overload with normovolemic anemia and result in significant fluid diffusion into interstitial space. In order to save the residual pump blood and reduce such ill effects and complications, we applied ultrafiltration on 40 pediatric cases during open-heart surgical procedures. Our clinical data, ultrafiltration application indications and recommended procedures are now presented.

Patients and Methods

Forty pediatric cases underwent corrective surgery for congenital heart disease during cardiopulmonary bypass utilizing ultrafiltration. Their diagnoses were tetralogy of Fallot (TOF) 12 cases, ventricular septal defect (VSD) 23 cases, atrial septal defect (ASD) 4 cases and partial atrioventricular canal (PAVC) 1 case. The patients' ages ranged from 10 months to 9 years (4.9±2.6 yrs) (25 cases<5 yrs, 62.5% and 15 cases>5 yrs, 37.5%) and body weight from 7 to 28 kgs (16.4±5.8 kgs)(18 cases<15 kgs, 45% and 22 cases>15 kgs, 55%).

All of the patients underwent cardiopulmonary bypass with hypothermia (25-28°C) and utilized a hollow fiber membrane oxygenator (made in Shanghai China). Eighteen (18) cases were primed with one unit of bank blood (200 ml) and 22 cases were primed with Ringer's Lactate solution without blood or plasma. During CPB, Ringer's Lactate solution was added as needed to maintain adequate flow rates or if the hemocrit value dropped to 15%, another unit of bank blood was added to the perfusate. Crystalloid cardioplegia was routinely used.

A TX-110 Dialyzer (made in Shanghai China) was the ultrafilter of choice for all cases. The TX-110 is composed of hollow cellulose acetate fiber with an internal diameter of 200 μm and a fiber wall of 15 μm. It has an effective surface area of 1.1 m² and its priming volume is 75 ml. The ultrafilter was interposed at one of the ports in the arterial filter of the CPB circuit as shown in Fig. 1. Before ultrafiltration, the ultrafiltrator was flushed with Ringer’s Lactate solution and heparin and then emptied by gravity before use. Ultrafiltration was performed during the rewarming period of CPB. Blood flow rate of the ultrafiltrator was maintained at 250-300 ml/min and the negative pressure applied to the ultrafiltrator was less than -250 mmHg (produced by a roller pump).

Results

In our group, the average CPB time was 70.6±25.7 min (38-122 min) and the ultrafiltration duration was 21.2±9.7 min (12-32 min). The fluid volume removed ranged from 210-560 ml (327±268 ml). The ultrafiltrability (total blood
were measured in 12 cases before and after ultrafiltration. Bypass may decrease the blood viscosity and improve tissue perfusion. However, with diluted perfusate there is fusion of dilute residual pump blood directly may cause fluid accumulation usually occurs with hemodilution postoperatively, especially in pediatric cases. Transfusion of dilute residual pump blood directly may cause circulatory overload in patients with normovolumic anemia and impair the recovery of hemodynamics postoperatively. In order to utilize residual pump blood and eliminate such ill effects and complications, dilute pump blood should be hemoconcentrated prior to transfusion. Ultrafiltration is one of the best methods. We have applied ultrafiltration to 40 pediatric cases during CPB since 1989. It was utilized for pediatric open-heart surgery, because of a small priming volume, controlled blood flow rate, and easy removal of plasma water. Ultrafiltration is an extracorporeal technique that makes use of the principle of convective solute transport across a semipermeable membrane and by which plasma water is removed from dilute blood during cardiopulmonary bypass. Our results showed that the volume of ultrafiltrate fluid was 327±268 ml, that the HCT of pump blood increased from 16.1±5.4% to 34.7±3.8%, and that the levels of electrolytes (K⁺, Na⁺, Cl⁻, Ca²⁺), BUN and creatinine of the ultrafiltrate fluid were similar to plasma. There was no protein within the ultrafiltrate fluid and its crystalloid osmotic pressure was a little higher than plasma. These results demonstrate that ultrafiltration may concentrate dilute blood and keep blood components during CPB effective and safe. In our group, the average ultrafiltrability was 11.2%(10.7-12.1%). It was similar to Zhou’s result. We consider that this is dependent upon the character of the ultrafilter. Five (5) cases (TOF, VSD and ASD) had hemoglobinuria in the ICU after transfusion of the ultrafiltered pump blood. We think that this may relate to the kinds of disease and red blood cells damaged by mechanical force (excessive negative pressure) during the ultrafiltration.

In our group, there were 22 cases with bloodless priming. Nine (9) cases with blood priming whose HCT values had dropped below 17% during CPB. Six (6) patients were administered digoxin and diuretics preoperatively. Three (3) cases underwent a total CPB time of more than 110 minutes. Therefore, we consider that the indications of ultrafiltration in pediatric cardiac surgery are: 1. The initial perfusion is conducted with bloodless priming or with blood priming when the HCT value dropped to lower than 17% during CPB (to prevent further increasing fluid accumulation in interstitial spaces). 2. The CPB time is longer than 2 hours (to prevent excess fluid balance). 3. The patient receives digoxin and diuretics preoperatively or has complex anomaly (to prevent heart dysfunction and diuretic-resistance postoperatively).

**Recommended Procedures**

1. The ultrafilter must be flushed in Ringer’s lactate solution and heparin prior to use, then emptied it to make ready.
2. Negative pressure should only be used while there is blood flowing through the ultrafilter so that there is a gradual build up of vacuum in the hollow fiber. The process is reversed to stop ultrafiltration (first the negative pressure is removed and then the blood flow is stopped).
3. The blood flow rate should not exceed 300 ml/min, the negative pressure should be controlled to less than -250 mmHg.
4. Monitoring the level of electrolytes and HCT values are required. Electrolytes should be within the normal range, especially potassium, and HCT value should not be higher than 40% after ultrafiltration.
5. During ultrafiltration, if the ultrafilter fluid’s flow is abnormally slow or the color of the ultrafiltrate fluid turns to pink, ultrafiltration should cease immediately. The ultrafilter should be changed.

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<th>Table 1. Lab parameters of pre- and post-ultrafiltration blood and ultrafiltration fluid (N=12)</th>
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Discussion

Hemodilution during hypothermic cardiopulmonary bypass may decrease the blood viscosity and improve tissue perfusion. However, with diluted perfusate there is a significant increase in extracellular and interstitial water. Fluid accumulation usually occurs with hemodilution CPB postoperatively, especially in pediatric cases. Transfusion of dilute residual pump blood directly may cause circulatory overload in patients with normovolumic anemia and impair the recovery of hemodynamics postoperatively. In order to utilize residual pump blood and eliminate such ill effects and complications, dilute pump blood should be hemoconcentrated prior to transfusion. Ultrafiltration is one of the best methods.

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Figure 1. The ultrafiltrator is inserted at the arterial filter line of the standard CPB circuit employing a membrane oxygenator.

Our experience has led us to the conclusion that ultrafiltration during pediatric CPB is facile, safe and effective. It may result in a reduced amount of fluid accumulation in extracellular fluid space with hemodilution perfusion which benefits the patient’s postoperative recovery.

References

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