Bloodless cardiopulmonary bypass for neonates and infants: an ultimate teamwork achievement

Hanna D. Golab-Schwarz

Department of Cardiothoracic Surgery, Erasmus MC, University Medical Center, Rotterdam, The Netherlands

In open heart surgery for neonates and small children, the cardiopulmonary bypass (CPB) circuit surface and the priming volume are relatively large in relation to patient size and blood volume. Therefore, use of allogeneic blood is inevitable to maintain the optimal haematocrit level during the bypass.

The deleterious effects of allogeneic blood transfusion are well documented in adult patients. Studies in adults demonstrated that low haematocrit was associated with postoperative renal dysfunction, but transfusion of red blood cells concentrate (RBCs) to compensate for haemodilution significantly increased the risk of renal impairment and failure [1,2,3]. This suggests that severe haemodilution during CPB may diminish systemic oxygen delivery and that allogeneic blood transfusion may worsen ischaemic organ injury. Silliman and associates have shown that blood transfusion is a major factor for post injury multi-organ failure and that the transfusion related morbidity positively correlated with the duration of blood storage [4]. Potassium level and free haemoglobin level from erythrocyte lysis increase with duration of blood storage as well as activated complement fragments and inflammatory cytokine levels (IL-8 and TNF-α) [5]. The importance of the elevated lactate levels measured in the stored blood in relation to the clinical outcome has not been established [6].

Recently, total avoidance of allogeneic blood during paediatric open heart surgery became strongly advocated. Commercially available minimized elements, an adjusted set up of the systems and paediatric dedicated heart-lung machines allow reduction of the amount of allogeneic blood in the prime and during the bypass. Consequently, in selected paediatric patients bloodless open heart surgery could be safely and successfully performed [7-10].

Still, there are additional measures needed to obtain asanguinous cardiopulmonary bypass for the majority of neonatal and infant patients. Selection of the most relevant requirements contains: the adjustment of acceptable haemodilution level during CPB, enhancement of patient preoperative haematocrit value and optimization of oxygen demand/supply monitoring during CPB.

Owing to general availability of continuous monitoring of mixed venous oxygen saturation (SVO_2), regional cerebral and systemic oxygenation (rSO_2) and frequent measurement of plasma lactate level during bypass, investigators were able to accept haemodilution levels as low as 20% during CPB for biventricular corrections and 25% for univentricular corrections in neonatal and infant patients.

If there were difficulties to maintain the SVO_2 above 70% and rSO_2 above 50%, despite increasing the pump flow and oxygen concentration during bypass, allogeneic blood transfusion was administrated. Similarly, when plasma lactate level was increased above 4.0 mmol/l blood transfusion was performed [11,12].

Directly after the cessation of bypass, patient haematocrit may be enhanced through modified ultrfiltration. Study of Kuratani and associates demonstrated that the advantage of modified ultrafiltration over conventional ultrafiltration consists of significant improvement of clinical conditions in the immediate post bypass period. On the other hand, the

postoperative outcome parameters were not significantly influenced by the type of ultrafiltration [13].

Pre-operative patient haematocrit is an important factor that strongly influences the level of haemodilution during asanguinous CPB. Since recombinant human erythropoietin (EPO) has become available for clinical use, it is successfully administrated in adult patients undergoing open-heart surgery to avoid transfusion of allogeneic blood [14]. Shimpo and collaborators proved that EPO is an effective adjuvant therapy for open heart surgery without blood transfusion in children [15].

Peri-operative administration of EPO, with or without predonation protocol, was concluded to be an effective strategy for bloodless heart surgery. On the downside, there are costs involved with EPO administration and predonation strategy (need for prolonged hospitalization) as well as physical and psychological stress for the patient. In addition, some patients, due to their cardiac conditions, cannot wait for this strategy to result in the desired, higher level of haematocrit.

In recent years, commercially available oxygenators, arterial line filters and haemofilters, designed to serve paediatric patient underwent consequent miniaturization. This process of technical refinement is still going on and the latest products are very promising. The newest oxygenators incorporate an arterial line filter thus further limiting priming volume (Terumo Capiox Fx 0.5, Maqet Quadrox – Neonate and Pediatric). Despite the availability of minimized system elements, the rest of the CPB circuit should be drastically reduced in volume. All technical measures to reduce priming volume result in such small neonatal and infant CPB circuits that their haemodilutional effects are markedly diminished. For example, Durandy and co-operators created a system of 120 ml volume for patients up to 10 kg [10], Merkle and associates used a circuit of 190 ml volume for children with a body weight under 6 kg [9], and Charette with associates reduced their CPB system to 172 ml [16].

As there is a general agreement that bloodless CPB for small children could be safely and successfully performed, a specific centre-related programme is required to achieve this objective. Institutional guidelines and multidisciplinary efforts undertaken in the pre- and postoperative period proved to be of great importance concerning bloodless heart surgery and should be seriously pursued by all involved healthcare professionals.

References

1. Karkouti K, Beattie WS, Wijeysundera DN, Rao V, Chan C, Dattilo KM, Djaiani G, Ivanov J, Karaski J, David TE. Hemodilution during cardiopulmonary bypass is an independent risk factor for acute renal failure in adult cardiac surgery. J Thorac Cardiovasc Surg 2005; 129: 391-400
2. Swaminathan M, Philips-Bute BG, Conlon PJ, Smith PK, Newman MF, Stafford-Smith M. The association of lowest hematocrit during cardioplulmonary bypass with acute renal injury after coronary artery bypass surgery. Ann Thorac Surg 2003; 76: 784-92
3. Habib RH, Zacharias A, Schwann TA, Riordan CJ, Durham SJ, Shah A. Adverse effects of low hematocrit during cardiopulmonary bypass in the adult: should current practice be changed? J Thorac Cardiovasc Surg 2003; 125: 1438-50
4. Silliman CC, Voelkel NF, Allard JD, Elzi DJ, Tuder RM, Johnson JL, Ambruso DR. Plasma and lipids from stored packed red blood cells cause acute lung injury in an animal model. J Clin Invest 1998; 101: 1458-67
5. Jacobi KE, Wanke C, Jacobi A, Weisbach V, Hemmerling TM. Determination of eicosanoid and cytokine production in salvage blood, stored red blood cell concentrates and whole blood. J clin Anesth 2000; 12: 94-9
6. Schroeder TH, Hansen M. Effects of fresh versus old stored blood in the priming solution on whole blood lactate levels during paediatric cardiac surgery. Perfusion. 2005; 20: 17-9
7. Durandy Y. Usfulnes of low prime perfusion pediatric circuit in decreasing blood transfusion. ASAIO journal 2007; 53: 659-661
8. Ando M, Takahashi Y, Suzuki N. Open heart surgery for small children without homologous blood transfusion by using remote pump head system. Ann Thorac Surg 2004; 78: 1717-22

9. Merkle F, Boettcher W, Schulz F, Koster A, Huebler M, Hetzer R. Perfusion technique for nonhaemic cardiopulmonary bypass prime in neonates and infants under 6 kg body weight. Perfusion 2004; 19: 229-237
10. Durandy Y. The impact of vacuum-assisted venous drainage and miniaturized bypass circuits on blood transfusion in pediatric cardiac surgery. ASAIO journal 2009; 55: 117-120
11. Ging AL, Onge JR St, Fitzgerald DC, Collazo LR, Bower LS, Shen I. Bloodless cardiac surgery and the pediatric patient: a case study. Perfusion 2008; 23: 131-134
12. Kotani Y, Honjo O, Nakakura M, Fujii Y, Ugaki S, Oshima Y, Yoshizumi K, Kasahara S, Sano S. Single Center Experience With a Low Volume Priming Cardiopulmonary Bypass Circuit for Preventing Blood Transfusion in Infants and Small Children. ASAIO J 2009; 55: 296-299
13. Kuratani N, Bunsangjaroen P, Srimueang T, Masaki E, Suzuki T, Katogi T. Modified versus conventional ultrafiltration in pediatric cardiac surgery: a meta-analysis of randomized controlled trials comparing clinical outcome parameters. J Thorac Cardiovasc Surg. 2011; 142: 861-7
14. Watanabe Y, Fuse K, Konishi T. Autologous blood transfusion wit recombinant human erythropoietin in heart operations. Ann Thorac Surg 1991; 51: 767-72
15. Shimpo H, Mizumoto T, Onoda K, Yuasa H, Yada I. Erythropietin in pediatric cardiac surgery. Chest 1997; 111: 1565-70
16. Charette K, Hirata Y, Bograd A, Mongero L, Chen J, Quaegebeur J, Mosca R. 180 ml and less: Cardiopulmonary bypass techniques to minimize hemodilution for neonates and small infants. Perfusion 2007; 22: 327-31