Strategies for optimisation of paediatric cardiopulmonary bypass

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Chapter 6 Summary and new prospectives

Since the first use of a heart-lung machine for total cardiopulmonary bypass on April 5, 1951 major changes took place. While the first two patients did not survive, today cardiopulmonary bypass related mortality is almost nil. The huge circuits with a bubble or film oxygenator requiring several litres of prime have been replaced with small membrane oxygenators and circuits that only require a few hundred millilitres of prime.

As more procedures were done the knowledge and long term follow-up of patients with congenital heart disease increased. Based on these new insights, more and more children are operated in the first days or weeks of their life since this seems to have a major impact on long term survival. However, this approach confronts the clinician with a lot of technical limitations when he has to place a neonate of 2 Kg on cardiopulmonary bypass. The often still immature organs demand for further research in order to keep bypass related damage to an absolute minimum.

A first major problem is that of vascular access. The small blood vessels of the child need to be cannulated without obstructing blood flow or damaging the vessel wall. What is the best design for obtaining this goal? How can one be sure that all organs are perfused, that the native heart will not be challenged by an additional afterload and that total venous return is directed towards the cardiopulmonary bypass? Appendix 1 focuses on the limitations and advantages of vacuum assisted venous return (VAVD) in small babies. VAVD makes it possible to enhanced venous return with approximately 10% mainly due to a larger pressure difference. Additionally, VAVD also allows to
use smaller cannulas resulting in less obstruction of the blood vessel and less damage to the blood vessel wall. The combination of smaller cannulas with VAVD might result in a larger operating field for the surgeon with less back flow.

For arterial re-infusion the design of a cannula is of main importance. Appendix 2 explains how arterial cannula design will affect jet formation while Appendix 3 points to the limitations of existing paediatric arterial cannulas. Large differences for their pressure flow characteristics were found based on deviations in internal diameter and design.

In paediatric cardiopulmonary bypass the oxygenator remains a problem because of his priming volume, large foreign surface area and not always optimal fluid dynamics. These problems are partly due to the fact that most if not all paediatric oxygenators are “downscaled” adult oxygenators and not specifically adapted for neonatal procedures. Appendix 4 represents the clinical benefits of an oxygenator specially designed for neonatal cardiopulmonary bypass. The use of such a neonatal oxygenator makes it possible to construct much smaller circuits resulting in less haemodilution. Appendix 5 gives the clinical impact on blood products when using a neonatal oxygenator in combination with a small circuit. The fluid dynamics in an oxygenator are important for achieving optimal mass transfer and haemocompatibility. Appendix 6 presents a new technique for the comparison of the pressure flow relationship in oxygenators with a different design. This approach makes it possible to make more objective decisions when
comparing different products. The impact of the new ELF membrane oxygenators on blood elements was studied in appendix 7.

One can question the use of an arterial filter in a paediatric circuit as it will enlarge total priming volume without adding any additional safety. Appendix 8 suggests that the hollow fibre stack of the membrane compartment might be an acceptable alternative since it will act as a depth filter and it is able to remove gaseous emboli. This alternative will reduce priming volume without jeopardising safety.

Control of the inflammatory response is a major goal for the paediatric team. One approach coating all artificial surfaces with a coating that biomimicks the outer layer of the cell membrane leads to a reduction in complement activation and a better platelet preservation. This is reported in a dog model in appendix 9 and confirmed in the clinical setting in appendix 10.

Unfortunately this coating does inhibit the inflammatory response completely and this might be explained by the findings of appendix 11 that blood coming from structures not covered with endothelium such as the pericardium and pleural cavities does activate the coagulation system. By doing so it will also activate the complement system and promote capillary leak.

**Clinical implications and possible future directions**

More and more new-borns with congenital heart disease are operated within the first days or weeks of life. As a result body weight can be very low and the anatomical structures will be small. Institution of cardiopulmonary bypass
under such conditions asks for dedicated cannulas with minimal deviation of the inner diameter. In order to achieve optimal venous drainage and arterial re-infusion under all circumstances, more designs and diameters should be developed. Pressure-flow diagrams based on viscous solutions such as water-glycerine should accompany these new designs as well as existing designs.

Vacuum assisted venous return in combination with dedicated venous cannulas will further reduce the total priming volume of the cardiopulmonary circuit and more importantly also reduce the “dead volume” in aspiration lines. As a result blood will be exposed to a lower amount of foreign material and less haemodilution of coagulation proteins and blood elements will occur. Due to the lower haemodilution less homologous products are needed and exposure to multiple blood donors can be avoided.

The treatment of all foreign material with a biocompatible coating will reduce inflammatory response.

Future developments should focus on

1. Membrane technology: microporous versus diffusive
2. Surface treatment of all foreign surface
3. Integration of components and miniaturisation of the cardiopulmonary bypass for further reduction of priming volume and foreign surface
4. Fluid mechanics of the complete cardiopulmonary bypass circuit combined with extensive modelling of the fluid mechanics in each component
5. Cannulas in combination with the physical and biological aspects of vascular access in general
6. Selective blood treatment for activated blood