Chapter 1 Introduction and aim of the thesis

The mortality associated with the repair of congenital heart defects in early life has decreased considerably over the years. However improved survival has unmasked a whole spectrum of morbidity associated with the practice of cardiopulmonary bypass [1].

As a general concept, cardiopulmonary bypass will temporarily bypass heart and lungs. This is achieved by introducing one or two venous cannulas in the venae cavae that direct venous return of the patient, by means of plastic tubing, into a reservoir. This reservoir replaces the compliance of the veins. From the reservoir blood is pumped through an artificial lung or oxygenator. The oxygenator heats or cools the blood and maintains physiologic blood gases. Subsequently the oxygenated blood is guided through an arterial filter and re-infused by means of an arterial cannula into the aorta. All these components need to be primed before cardiopulmonary bypass can be started. Apart of this life support, the circuit is designed to meet specific surgical needs. Most systems have one or more aspiration lines for the recuperation of blood losses in the surgical field, the unloading of the left ventricle and aspiration of blood from additional blood vessels such as a left superior vena cava or collateral blood vessels. In many institutions the cardioplegia delivery is also integrated into the cardiopulmonary bypass circuit.

During conduct of paediatric cardiopulmonary bypass quite drastic changes occur. Due to haemodilution by priming solutions and cardioplegia, the haematocrit varies between 20 – 35%. Most operations require a certain
amount of hypothermia. Depending on the specific procedure the actual blood temperature might vary between 15 and 38° C. As a consequence of these temperature and haematocrit changes, viscosity will change and thus influence tissue perfusion. Also blood flows will change depending on the surgical procedure from circulatory arrest to high flow (up to 150 mL/kg) in the rewarming phase.

It is often assumed that a paediatric cardiopulmonary bypass circuit is a miniaturised adult system. This is not correct. In contrast to adults the priming volume of even the smallest paediatric circuits will equal or exceed the total blood volume of a baby. At the same time blood of the child will be exposed to at least four times more foreign surface relative to an adult. The unique physiology of the neonate and his sometimes aberrant anatomy, leads to technical limitations and, therefore, makes the design and conduct of a dedicated paediatric cardiopulmonary bypass complicated.

The combination of a new-born at one hand and open-heart surgery and cardiopulmonary bypass at the other hand is quite challenging. The new-born is a fast developing organism with immature organs within which the organic systems are developing or maturing at different rate. Open-heart surgery and cardiopulmonary bypass represent an extreme stress to the functioning of these developing systems. Moreover, the response of those organs to this stress will be different from what is reported in adults. Children are definitively more prone to inflammatory response. Also neurological consequences of the developing brain are different from those observed in the developed or degenerating brain.
The small size of vascular and cardiac structures not only challenges surgical skills but also limit the possibilities for obtaining an optimal vascular access and a bloodless surgical field.

Due to this unique anatomical and physiological environment specially designed components have been developed. This research and development is expensive and will often reach the end spectrum of technical know how. Unfortunately, most of the time some industries are reluctant to invest in the paediatric domain because of the small numbers compared to the huge amount of adult cardiac procedures performed yearly.

Further research is also required to investigate the long and short-term influence of different surgical strategies and techniques for conducting cardiopulmonary on the different organ systems. Recent research clearly demonstrates a correlation between conduct of cardiopulmonary bypass and morbidity [2-6].

However, as pointed out by Jonas and Elliott [1], the consequences of a badly conducted paediatric cardiopulmonary bypass should not be underestimated as it may impact several decades. The child’s quality of life is likely to be markedly diminished. Yet that is only part of the potential disaster. Children have parents and relatives. Each will be affected by the poor outcome of cardiopulmonary bypass. One bypass disaster can ruin many lives.
Aim of the thesis

The aim of this thesis is to address different aspects of paediatric cardiopulmonary bypass in detail and to propose modifications in order to reduce cardiopulmonary bypass related morbidity and by doing so, improve patient outcome. We will focus on four major items: (1) vascular access, (2) mass transfer and fluid dynamics of oxygenators, (3) circuits and (4) whole body inflammatory reaction.

- The small vascular structures of the new-born demand a better design description of the geometry and fluid dynamic characteristics of cannulas. There is not only a need for a better validation of today’s cannulas but also for research into the relation between the hemodynamic characteristics of these cannulas and possible damage to blood elements.
- The oxygenator is prone to less optimal flow, due to its tortuous flow path, its large foreign surface area and the rapid changes in blood velocity resulting in non-optimal mass transfer and activation of the whole body inflammatory response. Additionally, most oxygenators have a priming volume that is too high compared to the total blood volume of a new-born. There is an urgent need for smaller, more blood compatible oxygenators, with optimisation of their fluid mechanics and gas exchange in order to fit the paediatric needs. These needs will include the capability for achieving subnormal arterial oxygen tensions in cyanotic children without compromising the high oxygen consumption of children during rewarming.
- Most circuits today have been designed based on empirically derived data. This results in large volumes in the arterial and venous lines as well as in
the aspiration lines. The use of an arterial line filter is highly recommended although it is not used in an appropriate way in most institutions.

- Finally, the use and conduct of a paediatric cardiopulmonary bypass will end in a mild or more pronounced whole body inflammatory reaction. The strength of this reaction will vary from child to child, the equipment used, and the conduct of the bypass.

We will propose techniques and strategies to overcome or to reduce these problems and by doing so to ameliorate the cardiopulmonary bypass related morbidity.

References