Perfusion techniques in minimally invasive setting

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Abstract: Further development and improvement of extracorporeal circulation (ECC) is paramount for the success in 'minimally invasive cardiac surgery'. This requires advance in underling technology as well as a special mindset and a high level of situation awareness of perfusionist in order to balance safe perfusion and providing optimal conditions for the surgeon to operate. The necessity of this balance influences all stages of preparing and performing the surgical intervention and involve selection of equipment, methods and level of control of patient's homeostasis and timely compensation for necessary deviations. There are examples presented: selection of heart-lung machine set and cannulation, and a choice of the method of preventing effective heart contraction during minimal invasive cardiac surgery. These examples demonstrate that decisions in minimal invasive setting is often a 'maze' choice with impact at all stages of intervention and all specialists involved. The team approach that coordinates efforts of the surgeon, anesthesiologist, perfusionist, and nurses is paramount to achieve the best clinical outcomes.

Keywords: Cardiac surgery; extracorporeal circulation (ECC); perfusionist; patient safety

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The current social developments stimulate introduction and fast expansion of 'minimally invasive cardiac surgery' (1). The minimizing of surgical trauma involves changing in access to the heart and requires using of special instruments and techniques. This often leads to an increase of the duration of cardiopulmonary bypass as well as an increase of aorta occlusion time, which could lessen the physiologic benefit of the procedure. In this situation, extracorporeal circulation (ECC) is becoming an important determining factor. ECC is a highly sophisticated process based on information obtained from sources such as ECC indicators, hemodynamic parameters, surgeons, an operating field, a scrub nurse, surgical instruments, and monitors (2). It is apparent that effective work in an increase complex environment requires a special mindset and a high level of situation awareness. The perfusionist must be ready to adapt ECC according to alterations in patient's condition as well as to changes in the operating field, in order to balance safe perfusion and providing optimal conditions for the surgeon to operate.

The necessity of this balance influences all stages of preparing and performing the surgical intervention, like for example selecting the ECC set for the heart-lung machine. Thus, minimizing surgical trauma also requires minimalizing the ECC circuit, where augmented venous drainage is an important feature. Two methods of augmentation of venous drainage exist, using three types of ECC sets, i.e., (I) open set with vacuum assisted venous drainage (VAVD); (II) closed system with kinetic assisted venous drainage (KAVD); and (III) minimized extracorporeal circuit (miECC). Each type has its benefits and drawbacks, which are discussed below.

The open set with VAVD is based on the contemporary hard-shell open reservoir with a low priming and dynamic volume (3) that is considered as an important factor for lessening deleterious effects of ECC (4). Additionally, open systems with VAVD are recognized to be easy to operate and therefore considered beneficial. The open systems with VAVD are the most robust and flexible systems in use. However, they have their snags. ECC with open systems mean continuous exposure to a large and complex surface that contains defoaming sponges and antifoam agents. The use of open-systems in comparison to close-systems is shown to be aggravation of the complement pathway activation, release of polymorphoneculocytes elastase, fibrin degradation products, thromboxane B2, and larger shed blood loss (5-8). In addition, open systems with VAVD are associated with an increase transmission of gaseous microemboli (9-13), venous line chattering (14), increased arterial to venous shunt in the circuit (15), and haemolysis (16,17). Moreover, numerous case reports and anecdotes of catastrophic events are described while using VAVD, such as overpressuring of the venous reservoir (9-13) or gas bubbles transgression in membrane oxygenators (18).

A second method to augment drainage uses a centrifugal pump in the venous line before the venous reservoir, also referred to as KAVD. Using KAVD as a closed system in combination with a soft-shell reservoir excludes the negative effects of an open system and complications of VAVD with a hard-shell venous reservoir. However, as well as with VAVD the augmented subatmospheric pressure in the venous line during KAVD, increases the chance for air entering the circulation, venous line chattering, and possible haemolysis (19).

Despite the fact that data describing the resistance to air in the venous line of open systems and closed systems are contradictory, air in venous line of both systems will pass to the arterial side with resultant transmission of gaseous micro-emboli (20). The relatively higher priming volume of the closed systems in comparison to the open systems, as well as the necessity of controlling an additional pump could be named as disadvantages of the closed system with KAVD. Furthermore, incorporation of an additional pump increases the system complexity and consequently the probability of increased user error (21).

miECCs s can be seen as a further development of the KAVD when a single centrifugal pump augments venous drainage and returns blood to the patient at the same time. In a recently published position paper from the Minimal invasive Extra-Corporeal Technologies international Society, it is stated that miECC has to be considered as part of minimally invasive cardiac surgery, which could maximize clinical benefits further improving patient outcomes (22). Operating miECC in combination with contemporary trends for controlling physiological parameters facilitates development of a "physiologically based" surgery (23-25). The beneficial effects miECC on morbidity and mortality are related to reduction of haemodilution, mediastinal bleeding, and inflammatory response, as well as the reduced blood transfusion requirements (22,26-32).

Evident benefits of minimized cardiopulmonary bypass (CPB) systems, however, do not come without consequences. The major limitation of these systems is absence of a venous reservoir, which in turn requires special volume management. According to Anastasiadis *et al.* teamwork is paramount as well as a learning curve involving at least 50 successful interventions in order to gain optimal results (33). Further, absence of a venous reservoir generates safety concerns of the circuit in cases of air entrainment or significant blood volume loss or sudden change of the surgery plan (23,34,35). Attempts to increase safety of miECC systems often lead to proliferation of system complexity, e.g., modification of the Medtronic Resting Heart System described by Fernandes *et al.* (36), or the modular AHEPA circuit design (23). Rise in complexity of a system could increase the chance for user and/or technical errors (21). Taking this in account, we developed a versatile minimized system that is in fact a KAVD open system where the hard-shell reservoir is bypassed using a so-called Better-Bladder that provides venous line compliance during augmented drainage, facilitating a rather simple and robust system (35).

The other, close related to the heart-lung machine set, question is the selection of cannulas and cannulation sites. The importance of these questions is reinforced by the obligate requirement of stable CPB and bloodless exposure of the valve for the success of MICS (37). Therefore, the choice of cannulation site and type of cannula should be done for each patient based on patient risk profile and with a backup plan. There are a substantial number of publications discussing benefits and disadvantages of numerous cannulation sites (37-45). Although extracorporeal circuit components can be considered harmless if used according to prescription, extensive cellular damage can be caused by the way the extracorporeal circuit is composed and managed (46). The cannulas as a narrowest part of heart-lung machine set may have great impact at the blood trauma. For any cannula exists a point beyond which the flow becomes at first disturbed and then, at increasing flow rates, it becomes turbulent. Although, the underlying mechanisms of turbulence induced trauma are not clear, it has been shown that at identical shear stress, turbulent flow produces far more blood trauma than laminar flow (47). In turn, haemolysis appears to be an important contributor to postoperative kidney injury and intestinal mucosal damage, potentially by limiting no-bioavailability (48). In addition, too small diameter of venous cannula will entail increased subatmospheric venous line pressures and causes direct damage of red cells (16) and gas emboli formation *de-novo* (35,49,50).

The challenge of proper cannulas selection amplified by most commonly used in the medical industry the French (Fr) (51) scale which describes only the outer diameter of catheter. Some information can be acquired from the flow-pressure curves presented by industry. However, these flow-pressure curves are based on the tests with water at room temperature. The prediction of blood flow through complex shapes of cannulas can only be done using computational fluid dynamics models which are complex and only possible using commercial packages (52). Even using of simplified methods, like 'M-number' (53,54) or methods based at the concept of dynamic similarity (55-58) is problematic. Unfortunately, there is not much attention in surgical world paid to the hydrodynamic, and available information can be misleading. For example, article "Systemic venous drainage: can we help Newton?" by Corno (19) contains 2 error, starting from inappropriate application of Poiseuille equation for describing flow in cannulas till a simple algebraic error.

So, low awareness in hydrodynamic and physiological consequences of using small diameter cannulas as well as fear of possible complications makes selection of proper cannulas rather challenging. However, in practice, femoral cannulation after a short learning curve has a low risk of complications (40,43). Furthermore, preoperative computed tomography angiogram or magnetic resonance angiography aids to predict hitches of cannulation and perfusion, and consequently prevent vascular complications (59,60).

The surgical choices like cannulation sites, type of arterial and venous cannulas is thus a complex task involving balance of surgical requirements, experience, and demand of minimizing possible harmful effects of ECC. Similar accounts for situations when the arts of extracorporeal technology are challenged by the necessity of balance between safe perfusion and optimal conditions for surgery, which include not only the components of circuit but also the long list of interrelated physiological parameters that are under the control of the perfusionist during CPB. The most important parameters are mean arterial blood pressure, systemic bypass flow rates, oxygen delivery, haemodilution and haematocrit values, systemic temperatures, pulsatile and non-pulsatile perfusion, and blood gas management (8,61), all to preserve homeostasis.

The way of preventing effective heart contraction during the minimal invasive surgical intervention is another example of laborious choice which affect not only the course of surgery, but also ECC.

Such easy answered question during open heart surgery with median sternotomy as myocardial protection becomes a multivariable selection challenge in minimally invasive approach. There are several methods to prevent effective heart contraction during minimal invasive cardiac surgery, which include infusion of a cardioplegic solution after external or endovascular aortic occlusion, induced fibrillation (62-66), and empty-heart beating described by several authors (67,68). The first three methods are in use in our centre.

The mild hypothermia is used in case of external cross-clamp of aorta, mean arterial pressure (70–90 mmHg) and blood flow (2.4–2.6 $L{\cdot}min^{-1}{\cdot}m^{-2}$) were controlled according to the patient's requirements.

Different perfusion technique required during surgery with endovascular aortic occlusion. The central body temperature decreased to 30 ℃. This allows to diminish blood flow till 1.9 $L{\cdot}min^{-1}{\cdot}m^{-2}$. Careful control of arterial pressure is essential (50–60 mmHg) to prevent migration of balloon.

Artificial heart fibrillation can be used as a primarily choice or as forced measure due to aortic cross-clamp failure. With this approach the central body temperature decreased to 28 ℃. However, it is possible to maintain flow close to 2.4 $L{\cdot}min^{-1}{\cdot}m^{-2}$ and arterial pressure in range 70–90 mmHg. In case of grade 1 aortic insufficiency, it is necessary to keep lower mean arterial pressure with multiple decreasing of blood flow down to complete stop for a few minutes to provide conditions for surgeon to operate. Adequate reperfusion after each necessary stop of flow and hypothermia 28 ℃ allows avoiding lactate accumulation and metabolic acidosis.

The two examples above demonstrate that decisions in cardiac surgery in particular in minimal invasive setting is often a 'maze' choices with impact at all stages of intervention and all specialists involved. The team approach that coordinates efforts of the surgeon, anaesthesiologist, perfusionist, and nurses is paramount to achieve the best clinical outcomes. The principle that the surgeon should automatically be the "captain of the ship" is no longer tenable. Today, every healthcare worker is held accountable for his or her own actions, and as mentioned, skills are not necessarily interchangeable between groups (69). The area of responsibility of perfusionist requires a high level of system awareness and fast decision making. System awareness is a function of individual information processing, innate abilities, experience, and training (70), but also includes explicit and tacit knowledge, and fast deductive reasoning (71). These together with communicative skills are the qualifications necessary to become a valuable member of a multidisciplinary and inter-professional cardiac team.

Conclusion. ECC is a highly sophisticated process which requires fast analysis of all available information and timely reaction in order to balance safe perfusion and providing optimal conditions for surgeon to operate. The dedicated team approach that coordinates efforts of the surgeon, anaesthesiologist, perfusionist, and nurses is paramount to achieve the best clinical outcomes.

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Footnote

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