SHORT COMMUNICATION

The use of modern monitoring techniques and methodologies in conducting extracorporeal circulation: a place for Quantum Heart Lung Machine

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Introduction Extracorporeal circulation (ECC) is the standard of every cardiac surgery department. Despite numerous improvements in equipment and perfusion technique, cardiopulmonary bypass (CPB) is still one of the most demanding surgical procedures. However, existing ECC guidelines are not based on evidence-based medicine.[1] Every cardiac surgical unit has developed its own protocol for maintaining ECC with a defined value of perfusion pressure, pump flow rate, and blood hematocrit level. Recently, along with the technological development in the field of patient monitoring on CPB, a new perfusion concept based on the optimization of tissue oxygen delivery has been introduced. A number of serious CPB-related complications, such as an increased risk of ischemia-reperfusion injury, inflammatory reactions, hemorrhagic disorders, end-organ dysfunction, and vasoplegic syndrome, are associated with inadequate organ perfusion and thus underline the importance of suitable perfusion.[1,2]

According to the current standard, the target of blood flow is calculated on the basis of the patient's body surface area and is set at a level of 2.2 to 2.4 l/min/m^2. The mean arterial pressure is maintained in the range of 50 to 100 mm Hg either by increasing the hematocrit or by using vasoconstrictors. The nadir perfusion pressure in normothermia is defined by the autoregulation of brain blood flow with its lowest value of 50 mm Hg.[3] The threshold for partial pressure of oxygen (PaO_2) ranges from 150 to 160 mm Hg, lactate levels are kept within normal limits, and normocapnia is maintained. For patients with persistent hypertension and severe atherosclerosis, it is recommended to maintain relatively higher (>70 mm Hg) perfusion pressures.[1] The inherent hemodilution, which occurs after the crystalline priming, is associated with the general approval of relatively low levels of hemoglobin and hematocrit, above 7 g/dl and 21%, respectively.[1,4,5]

According to a new concept, tissue oxygen delivery (DO_2) and its extraction during CPB may be the elemental parameter determining the sufficient and safe tissue perfusion. It is calculated using the following formula: DO_2 = pump flow × [(hemoglobin × SaO_2 × 1.36) + (0.003 × PaO_2)]. DO_2 is directly proportional to blood oxygen content and the pump flow rate. The rationale behind the implementation of the new concept is the emerging results of clinical trials, in which the comparison of the new strategy with existing ECC standards revealed clearly better outcome and reduction in postreperfusion organ dysfunction.[6-8] The DO_2 threshold above the range of 280 to 300 ml/min/m^2 is the basic determinant of goal-directed perfusion (GDP).[6]

The aim of this report was to draw attention to the extremely important part of a cardiac surgery procedure, namely, ECC, and to present our

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experience with the new strategy of ECC management based on GDP. The expansion of controlled CPB parameters in terms of clinical observations with aspects of oxygen supply, extraction, and its consumption is required to introduce the new concept. We analyzed the process of increasing DO_2 both by adjusting the previously unchangeable pump flow rate and magnifying the oxygen content in arterial blood.

TABLE 1 Demographic data and intraoperative characteristics of the patient group (n = 22)

Parameter		Value
Age, y		57.2 (16.2)
Male sex, n (%)		15 (68.2)
BSA, m^2		1.98 (0.18)
Body mass index		28.17 (5.21)
Type of surgery, n (%)	Single procedure	14 (63.6)
	Double procedure	8 (36.4)
Bypass time, min		91.5 (31.9)
Cross clamp time, min		69.4 (31.5)
Blood transfusion, n (%)		3 (13.6)
SvO_2, %		73.3 (3.1)
Hemoglobin, g/dl		10.1 (1.1)
Hematocrit, %		30.3 (3.4)
Arterial temperature, °C		30.4 (7.1)
FiO_2, %		55.6 (3.7)
Sweep, l/min		2.7 (0.5)
$ecVCO_2$, ml/min		126.6 (35.1)
$ecVCO_2i$, ml/min/m^2		66.7 (17.6)
$ecDO_2$, ml/min		597.9 (95.8)
$ecDO_2i$, ml/min/m^2		314.7 (40.5)
$ecVO_2i$, ml/min/m^2		82.9 (9.3)
PCO_2@temp, mm Hg		41.3 (2.12)
PO_2@temp, mm Hg		182.7 (21.4)
Cardiac index (BSA), l/m^2/min		2.3 (0.1)
Arterial flow, l/min		4.4 (0.3)
Venous flow, l/min		4.4 (0.3)
Arterial pressure, mm Hg		142.4 (19.7)
Venous pressure, mm Hg		59.4 (47.3)
$FeCO_2$, %		4.6 (0.6)

Data are presented as mean (SD) unless otherwise indicated.

Abbreviations: BSA, body surface area; $ecDO_2$, oxygen delivery; $ecDO_2i$, oxygen delivery indexed to body surface area; $ecVCO_2$, carbon dioxide production; $ecVCO_2i$, carbon dioxide production indexed to body surface area; $ecVO_2i$, oxygen consumption index; $FeCO_2$, fraction of end tidal carbon dioxide; FiO_2, fraction of inspired oxygen; PCO_2@temp, partial pressure of carbon dioxide adjusted for temperature; PO_2@temp, partial pressure of oxygen adjusted for temperature; SvO_2, percentage oxygen saturation of venous blood

Methods This study was conducted on patients who underwent elective cardiac surgery with the use of Quantum Heart Lung Machine (Spectrum Medical, Gloucester, United Kingdom) at Wroclaw University Hospital between March and December 2018. All the procedures were approved by the local Bioethics Committee. The induction of general anesthesia was achieved with propofol, sufentanil, and rocuronium and maintained with sevoflurane insufflation in a 50% oxygen and air mixture and infusion of sufentanil and rocuronium. Anticoagulation was achieved by administering a sufficient dose of heparin (300 IU/kg) monitored using an activated clotting time exceeding 480 seconds. Arterial and venous flow and saturation values were registered by calibrated sensors on the arterial and venous line. Single-dose antegrade del Nido cardioplegia was used in all cases, with additional doses if considered necessary by the surgeon. While on bypass, the mean arterial pressure was continuously monitored and maintained above 60 mm Hg. Arterial pump flow based on body surface area and temperature with the initial value of 2.4 l/min/m^2 at normothermia was set for all patients. The red blood cells transfusion was triggered by the hematocrit value, mixed venous oxygen saturation lower than 68%. The perfusionists aimed to maintain the desired DO_2 above 280 ml/min/m^2.[6]

Data collection and statistical analysis During the procedure, all perfusion-related data were collected at 10-second intervals and registered at Quantum Workstation via the VIPER data management system. Descriptive data were expressed as mean values with either the standard deviation for continuous variable data or the percentage of the total for categorical data.

Results and discussion By the time of the data analysis, a total of 22 patients (mean [SD] age, 57.2 [16.2] years; men, 68%) operated on between March and December 2018 were included. The mean (SD) DO_2 was 314.7 (40.5) ml/min/m^2, whereas nadir DO_2 of less than 280 ml/min/m^2 occurred in 4 patients (18%). The mean (SD) hemoglobin concentration was 10.1 (1.1) g/dl (range, 7.4–11.9 g/dl). The mean (SD) hematocrit during CBP was 30.3% (3.4%), with the lowest and the highest values of 22% and 35.7%, respectively. The detailed demographic and intraoperative characteristics of the study group are presented in TABLE 1. Of the 3 patients (14%) who received packed red blood cell transfusion, 2 patients required the transfusion due to significantly low DO_2 levels, of 160 ml/min/m^2 and 200 ml/min/m^2, respectively. The third patient

received the transfusion to fulfill reservoir of the heart-lung machine. The mean (SD) arterial pump flow rate was 2.3 (0.1) l/min/m^2 (range, 2.0–2.5 l/min/m^2), while the patient-calculated arterial flow was 4.6 (0.3) l/min.

The new concept of perfusion based on the continuous monitoring of oxygen supply, its extraction, carbon dioxide production, perfusion pressure, metabolic parameters such as lactate levels, and diuresis contributed to the creation of GDP.[1,2,6] There is no strictly defined critical value of DO_2; however, according to some studies conducted on cardiac surgery patients, the nadir of 280 ml/min/m^2, below which metabolic (lactic) acidosis begins to develop, was established.[2] In this report, we present our remarks and early experience in continuous monitoring of patients' vital parameters during ECC. According to the concept of GDP, our perfusionists conducted ECC by optimizing DO_2 with a mean oxygen delivery indexed to body surface area of 315 ml/min/m^2. We also focused on adequate oxygen extraction and venous blood saturation. The measurements did not include carbon dioxide production due to its constant insufflations into the operating field.

The new ECC concept was captured mainly by a high level of oxygen content in arterial blood and by avoiding excessive hemodilution. In order to improve the oxygen supply, the pump flow rate was accelerated, yet only to a small extent, up to 2.5 l/min/m^2. This might have been due to the perfusionists' habit to maintain a constant pump flow rate. The advantage of continuous patient monitoring, as opposed to arterial blood gases previously performed at 30-minute intervals, is the ability to lead GDP. We believe that our initial observations will generate discussions and contribute to the development of more physiological ECC protocols. However, further research is needed to develop new ECC guidelines in which the procedure of cardiac surgery might become safer for patients and result in fewer complications and lower morbidity and mortality rates.

ARTICLE INFORMATION

CONFLICT OF INTEREST None declared.

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