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Review

The "benefits" of the mini-extracorporeal circulation in the minimal invasive cardiac surgery era

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ABSTRACT

Mini-extracorporeal circulation (MECC) constitutes a novel miniaturized cardiopulmonary bypass (CPB) circuit, heparin-coated and primed with aprotinin. Its membrane oxygenation is similar to conventional cardio-pulmonary bypass (CCPB), but it is a completely closed-volume system due to the lack of the venous reservoir which has been removed. In a mini circuit, the reservoir is the patient himself. Consequently, air entering the venous cannula is avoided. Nevertheless, the capabilities of MECC have been expanded either by the inclusion of a suction device that is only activated on direct contact with liquid in some circuits or by postoperative autotransfusion of the wrecked erythrocytes by a separate suction device with a cell-saver. Although the tubing diameter is similar between the two systems, the tubing length of the MECC is around half that of the CCPB, resulting in the restriction of priming volume. As a consequence, a higher hematocrit thus a limited need for perioperative blood transfusion is achieved due to less hemodilution. In addition, the inflammatory response is also diminished as a result of less artificial surface area interacting with blood. Finally, a lower dose of heparin is required prior to MECC than prior to CCPB.

Contents

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Introduction

Since 1953, when cardiopulmonary bypass (CPB) was introduced in medicine for the restoration of a large atrial septal defect in an 18-year-old woman [1], the equipment and methods have significantly developed leading to the gold standard in perfusion, the conventional cardio-pulmonary bypass (CCPB) [2]. CCPB enables not only low mortality rates and appears to be safe [3,4], but also provides a blood-free field for cardiac operations [2].

However, CPB is accompanied by various complications exacerbating the postoperative morbidity [5], which is relatively high. More than a third of the patients experience undesired effects due to coronary artery bypass grafting (CABG) [6]. CCPB can induce an inflammatory response and activate the coagulation process [2,7], which in combination with organ dysfunction leads to arrhythmias, neurological disorders, prolonged bleeding, or thromboembolism [8,9]. Hemodilution and transfusion of blood products reinforce the detrimental effects of CCPB [10].

Although beating heart revascularization (off-pump coronary artery bypass, OPCAB) was a first thought in order to avoid these effects, cerebrovascular complications and survival were not significantly improved [2]. Moreover, technical difficulties are an additional obstacle in reaching satisfactory graft patency [11], let alone that not all "open-heart" procedures can be performed "off-pump" [2]. Within the past decade, many innovations led to the introduction of mini bypass extracorporeal circuits for CPB [12].

The minimal extracorporeal circulation (MECC) restricts the systemic inflammatory response syndrome (SIRS) via limiting the blood–air interface, decreasing the artificial tubing length [2] and being more biocompatible thanks to complete heparin coating of the circuit [10,13]. Preservation of a higher hematocrit during CPB due to less hemodilution, decreased blood and blood products transfusion, and limited postoperative blood loss are some additional advantages of MECC. The final result is less end-organ damage, including the myocardium and the lungs [14,15]. Thus, MECC has been successfully applied in CABG as well as in some cases of aortic valve replacement (AVR) [7,16–18].

What is MECC?

Generally, MECC constitutes a novel miniaturized CPB circuit, heparin-coated and primed with aprotinin [19]. Its membrane oxygenation is similar to that of CCPB, reaching 7 L/min, whereas its gas exchange surface area is as large as 2.4 m^2 [5]. According to Mulholland et al. [20], 10–15 operations are enough to be safely performed and as many as 50 MECC procedures suffice for optimal knowledge to be gained.

MECC procedures have some significant differences compared with CCPB. It is a completely closed-volume system due to the lack of the venous reservoir which has been removed [2,5,7,19]. In a mini circuit, the reservoir is the patient himself, so venous return indicates cardiac output [21]. Consequently, air entering the venous cannula is to be avoided mandatorily [2]. Absence of a blood–air interface in the reservoir due to lack of the latter decreases the contact of blood with artificial components [22], blood is not available for direct reinfusion; thus, suction devices are not included. Nevertheless, the capabilities of MECC have been expanded either by the inclusion of a suction device that is only activated on direct contact with liquid in some circuits or by the postoperative autotransfusion of the wrecked erythrocytes by a separate suction device with a cell-saver [2]. Moreover, MECC circuit does not include the cardioplegia delivery system either [5].

Another determinant difference when the MECC and the CCPB are compared is the circuit length [2,5]. Although the tubing diameter is similar between the two systems, the tubing length of the MECC (80 cm) is around half that of the CCPB (150 cm) [23], resulting in the restriction of priming volume (450–900 ml vs. 1400–2200 ml relatively) [2,5,22,23]. As a consequence, a higher hematocrit thus a limited need for perioperative blood transfusion is achieved due to less hemodilution [2,5,19]. In addition, the inflammatory response is also diminished as a result of a less artificial surface area interacting with blood [2]. Finally, a lower dose of heparin is required prior to MECC (150–200 IU/kg) than prior to CCPB (300 IU/kg) [2].

Where is MECC applied?

Although the selection criteria for MECC surgery instead of CCPB differ widely from center to center, high-risk patients tend to be excluded from MECC, as it is principally performed in isolated CABG cases [5]. Aortic valve replacement via MECC has also been reported [10,23]. MECC has also been used in isolated cases of CABG with AVR [23], redo surgery ($n = 3$) [22], atrial septal defect closure [24], mitral procedures ($n = 5$) [22], and thoracoabdominal aortic aneurysm repair [25].

Deleterious effects of CCPB

An SIRS, causing platelet degradation and cytokine production affecting all organs, is the most detrimental effect that CCPB can induce [6,7,26]. The blame for this inflammatory response is in some measure put on the interaction between blood components and the various artificial surfaces within the CCPB apparatus, the blood–air interface, and the harm of shedding pericardial blood [2,7]. Coagulation disorders resulting in increased postoperative bleeding, arrhythmias, endothelial dysfunction with increased capillary permeability, prolongation of ventilation support, neurological complications, and multi-organ failure are potential results of CCPB-induced SIRS [7,26–28].

Moreover, patients after CCPB are prone to have significantly lower postoperative hemoglobin and hematocrit due to the large priming volumes that this method requires [2]. This hemodilution potentially affects hemostasis, decreasing levels of coagulation and fibrinolytic proteins [15]. Additionally, the risk of long-term morbidity and short-term mortality is increased by hemodilution [29]. Increased blood transfusion is often required due to excessive hemodilution [30] to provide adequate oxygen delivery to the vital organs [2]. Mechanical damage to red blood cells by the roller pumps can also be a reason why transfusion is needed [31]. However, blood transfusion as well as homologous blood products, apart from the hazard of transfusion-related diseases, appears to both contribute to the increase of postoperative long-term morbidity and mortality and worsen health-related quality of life [32]. The potential final result of all the aforementioned is end-organ dysfunction or failure and neurological dysfunction [15,31].

Clinical comparisons of MECC with CCPB

Mortality

According to current literature, early survival rates are not significantly altered by MECC compared with CCPB and OPCAB [13,16,33–35]. CCPB is associated with 30-day mortality rates ranging from 1.5% to 2%, whereas those of MECC range from 1.25% to 4% (p = ns) [5]. In a recent study, the overall 30-day mortality after CABG with MECC being of the order of 2.3% (1.1–13%) was even significantly better than CCPB [36]. No significant changes in intraoperative or hospital mortality after MECC compared with CCPB are observed either [22–24,37]. Moreover, according to a 236-case study with additive euroscore ≥6, even in these high-risk patients,