Minimal Extracorporeal Circulation: An Alternative for On-Pump and Off-Pump Coronary Revascularization

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Background. **Coronary artery bypass surgery employing minimal extracorporeal circulation (MECC) was compared with standard extracorporeal circulation (ECC) and off-pump coronary artery bypass graft surgery (OPCABG) with regard to the perioperative course.**

Methods. **From January 2004 to December 2007, 1,674 patients (n = 558 MECC, n = 558 ECC, n = 558 OPCABG) who underwent coronary bypass surgery were studied. The primary end point was in-hospital mortality; secondary end points were perioperative variables, intensive care, and in-hospital course.**

Results. **Demographic data, comorbidity, and the European System for Cardiac Operative Risk Evaluation score (MECC 3.0%, ECC 3.5%, OPCABG 3.2%) were similar among the groups, but in-hospital mortality for elective and urgent/emergent patients was lower in the MECC and OPCABG groups (MECC 3.2%, OPCABG 3.7%, ECC 6.9%; $p < 0.05$). The number of distal anastomoses was lowest in the OPCABG group, but comparable for MECC and ECC patients. Postoperative ventilation time, release of creatinine kinase, catecholamine therapy, drainage loss, and transfusion requirements were lower in the MECC and OPCABG groups, whereas stay in the intensive care unit was shorter only in the latter ($p < 0.05$).**

Conclusions. **Minimal extracorporeal circulation is an easy and safe procedure for coronary artery bypass graft surgery. In selected patients, the advantages of MECC equal those of OPCABG. MECC should be considered as an alternative to OPCABG and standard ECC procedures.**

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Coronary artery bypass graft surgery (CABG) with extracorporeal circulation (ECC) is the gold standard for multivessel coronary artery disease [1, 2]. Neuropsychological studies on the side effects of the use of ECC have led to a tremendous increase in off-pump coronary artery bypass graft surgery (OPCABG) and minimally invasive direct coronary artery bypass procedures during the last years [3]. Presumed advantages of these surgical techniques include lower in-hospital mortality, reduced morbidity, lower costs because of shorter hospital stay, and superior patient comfort in comparison with on-pump revascularization [4, 5]. However, OPCABG was also reported to be associated with lower bypass patency rates and a higher incidence of incomplete revascularization. Furthermore, arrhythmia and ischemia may lead to hemodynamic instability during OPCABG surgery [6–9]. The discussion with regard to the role of off-pump surgery remains controversial, and proper patient selection still seems to be essential for successful OPCABG procedures [10].

Initially, the minimal extracorporeal circulation (MECC) system was developed to allow safe and complete beating-heart revascularization; in other words, to maintain the benefits of beating heart surgery and to minimize the disadvantages of on-pump revascularization [11]. Later, the possibility of using Calafiore's blood cardioplegia was devised. Then, safe and reproducible CABG surgery on the arrested heart became feasible. Several clinical studies have shown that the harmful side effects of ECC such as systemic inflammatory response, blood cell trauma, hemodilution, coagulopathy, and neurologic deficits were clearly reduced with the MECC system [12–14].

In this study, we compared the perioperative course and outcome of CABG patients who were operated on using the three different techniques: MECC, standard ECC, and OPCABG.

Patients and Methods

After approval by the local Ethics Committee and informed consent of the patients, 1,674 patients of 2,416 patients who underwent elective, urgent/emergent, and

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Abbreviations and Acronyms

ACT = activated clotting time
CABG = coronary artery bypass graft surgery
CK = creatine kinase
ECC = extracorporeal circulation
EuroSCORE = European System for Cardiac Operative Risk Evaluation
ICU = intensive care unit
MECC = minimal extracorporeal circulation
OPCABG = off-pump coronary artery bypass graft surgery

redo isolated CABG from January 2004 until December 2007 were analyzed in a prospective manner. A median sternotomy approach was taken in all patients. Combined valve or aortic procedures were excluded from this study, as were patients who had heparin-induced thrombocytopenia. There were no restrictions with regard to the MECC procedure, apart from aortic valve insufficiency or a body mass index greater than 30 kg/m^2. During the study period, every cardiothoracic surgeon was familiar with the MECC, ECC, and OPCABG techniques; and it was up to the surgeon's discretion which procedure was used. Indication for CABG was established on the basis of published guidelines [15].

Demographic data, patient comorbidity, and predicted operative mortality for the patients (European System for Cardiac Operative Risk [EuroSCORE]) are shown in Table 1. The primary end point of our study was the in-hospital mortality rate in the three groups. Secondary end points were intraoperative variables (number of distal anastomoses, aortic cross-clamp time, and reperfusion time), blood/serum measurements (creatinine kinase, hemoglobin, serum creatinine, lactate), and intensive care (ventilation time, use of blood components, catecholamine dosage, drainage loss, intensive care unit stay) and in-hospital course (symptomatic transitory psychotic syndrome, post-operative dialyses, in-hospital stay). Time points (T) assessed were preoperative status (T0), 30 minutes after arrival on the ICU (T1), and 6 hours after surgery (T2).

CABG With Standard ECC and Cardioplegia

The bypass circuit of the standard ECC consisted of a heparin-coated tube system. A two-stage cannula (39F to 50F [Stöckert, Munich, Germany]), to drain the venous blood from the right atrium, and a 22F aortic cannula (Maquet, Rastatt, Germany) for the distal ascending aorta were used. The tubes were primed with a balanced colloid/crystalloid solution (500 mL Jonosteril [Fresenius, Bad Homburg, Germany], 500 mL Gelafundin [B. Braun, Melsungen, Germany], and 200 mL 20% Mannitol [Serag-Wiessner, Naila, Germany]). A nonpulsatile HL 30 Roller Pump (Maquet) established a blood flow of 2.4 L $\cdot$ min^{-1} $\cdot$ m^{-2}. During cross-clamping, a single shot of crystalloid HKT Bretschneider cardioplegia (Franz-Koehler-Chemie, Alsbach-Hähnlein, Germany) or of Calafiore's blood cardioplegia was applied to initiate cardiac arrest according to the surgeon's preference. Blood was collected in an open cardiotomy reservoir and transfused back to the patient. In the standard ECC group, a Quadrox 2000 (Maquet) or a Hilite 7000 (Medos, Stolberg, Germany) oxygenator was used.

CABG With MECC and Cardioplegia

The MECC is a fully heparinized, closed loop circuit without blood air contact (Fig 1). The components of the system included a membrane oxygenator (Quadrox D, Maquet; or Hilite 7000 CT, Medos), a centrifugal pump, a table line (3/8 [180 cm]), a venous two-stage cannula (32F to 40 F), and an aortic cannula (21F). In case of severe

Table 1. Demographic Data

	ECC	MECC	OPCABG	*p* Value[a]
Number of patients	558	558	558	
Mean age, years	66.8 ± 8.7	67.5 ± 8.8	66.8 ± 9.5	0.37
Male (%)	442 (79.6)	412 (74.3)	415 (75.4)	0.08
EuroSCORE, %	3.5 (1.7–6.7)	3.0 (1.8–5.7)	3.2 (1.8–5.7)	0.14
Ejection fraction, %	57.0 ± 15.0	58.0 ± 15.0	55.0 ± 16.0	0.002[b]
Body mass index, kg/m^2	28.8 ± 4.1	27.6 ± 3.8	28.6 ± 4.3	0.001[c]
COPD (%)	49 (8.7)	52 (9.3)	52 (9.3)	0.93
Peripheral vascular disease (%)	49 (8.7)	33 (5.9)	37 (6.6)	0.15
Arterial hypertension (%)	454 (81.4)	459 (82.2)	471 (84.4)	0.38
Atrial fibrillation (%)	30 (5.4)	20 (3.6)	22 (3.9)	0.29
Diabetes mellitus (%)	205 (36.7)	178 (31.9)	172 (30.8)	0.08
Serum creatinine (%)	1.0 (0.8–1.22)	0.95 (0.8–1.2)	0.98 (0.8–1.2)	0.06

[a] The *p* values represent the group statistics (analysis of variance or Kruskal-Wallis test). [b] OPCABG-MECC: 3% (1.5–5.5), $p < 0.001$. [c] One-way ANOVA.

ANOVA = analysis of variance; COPD = chronic obstructive pulmonary disease; ECC = extracorporeal circulation; EuroSCORE = European System for Cardiac Operative Risk Evaluation; MECC = minimal extracorporeal circulation; OPCABG = off-pump coronary artery bypass graft surgery.