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Minimal versus conventional cardiopulmonary bypass: assessment of intraoperative myocardial damage in coronary bypass surgery

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Abstract

Objective: Minimal extracorporeal circulation (mini-ECC) is a new technology, consisting of a centrifugal pump, an oxygenator, and a modified suction system. The main advantage of mini-ECC is the reduction of tubing length (reduction of the priming volume). Additional beneficial effects are a decrease of coagulation cascade and a reduction of blood transfusion in patients undergoing coronary artery bypass grafting (CABG) surgery. We compared the intraoperative and early postoperative myocardial damage and outcome of patients who underwent CABG surgery with conventional cardiopulmonary bypass (CPB) or mini-ECC. **Methods:** One hundred and thirty-six consecutive patients who underwent isolated CABG surgery at our institution were prospectively studied. Fifty-four patients (39.7%) were operated with mini-ECC. Patient characteristics were similar in both groups. The most interesting intraoperative details as well as in-hospital outcome were assessed. **Results:** There was no difference in mortality between the two groups. Cross-clamping time was similar in both groups ($p = 0.07$). Defibrillation was required in one patient in the mini-ECC group (1.9%) and in 38 patients (46.3%) in the CPB group ($p < 0.001$). In the mini-ECC group, the requirement of inotropic support and incidence of atrial fibrillation was significantly lower than in the CPB group. Postoperative creatine kinase isoenzyme MB (CK-MB) and cardiac Troponin I (cTnI) were significantly lower in the mini-ECC group ($p < 0.05$). Duration of ventilation, length of stay in the intensive care unit and total hospitalization time were significantly shorter in patients operated with mini-ECC ($p < 0.05$). **Conclusion:** Mini-ECC is a safe procedure and is followed by a diminished release of CK-MB and cTnI than after CPB. Postoperative recovery is accelerated following mini-ECC and there is a significantly lower incidence of postoperative atrial fibrillation.

Keywords: CABG surgery; Myocardial protection; cTnI; Minimal extracorporeal circulation

1. Introduction

Coronary artery bypass grafting (CABG) using cardiopulmonary bypass (CPB) is still the most accepted technique to treat coronary artery disease surgically. It is a safe and established technique with a low mortality rate [1,2]. However, the morbidity attributed to CPB is still significant [3—5]. Besides neurological events, which may at least be partially related to the use of CPB, and the inflammatory response, the ideal myocardial protection is still a matter of debate during CPB.

Cardiac Troponin I (cTnI) has been shown to be a sensitive and specific marker of myocardial damage during open heart surgery [6—8]. Additionally, cTnI is a reliable prognostic marker, and high cTnI-values have been shown to be associated with a worse mid-term outcome than lower values [8]. CABG on the beating heart (OPCAB) has gained popularity as an alternative to CABG with conventional CPB because all potential complications related to CPB may be eliminated. OPCAB significantly reduces postoperative cTnI-levels in comparison to coronary revascularization using cardioplegic arrest [9].

The minimal extracorporeal circulation (mini-ECC) system consists of a centrifugal pump, a membrane oxygenator, and an integrated optoelectrical suction system. The circuit has a reduced tubing length because the cardiotomy reservoir and the conventional suction device have been eliminated. The decrease in priming volume from 1800 to 600 ml helps to reduce the negative effects.

The aim of the present study is to compare perioperative myocardial damage observed with conventional CPB or with mini-ECC in patients undergoing isolated myocardial revascularization.

2. Patients and methods

2.1. Patients

One hundred and fifty-four patients who underwent primary isolated CABG surgery at our institution were

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prospectively studied. All other CABG operations (combined with valve surgery and/or aortic surgery) and redo CABG were excluded, as mini-ECC is actually used in our institution only in patients undergoing isolated CABG surgery. The decision whether or not to use CPB or mini-ECC depended on the availability of the system and on the surgeons preferences. However, to avoid selection bias, 40 patients were prospectively randomized to either receive CPB or mini-ECC. The protocol was accepted by the local ethical committee and all patients gave informed consent.

2.2. Operative technique

Surgery was performed through median sternotomy. After heparinization (mini-ECC: 200 IU/kg, CPB: 300 IU/kg) cardiopulmonary bypass was installed with an arterial cannula in the distal ascending aorta and a two-stage venous cannula inserted through the right atrium or by bi-caval cannulation in case a patent foramen ovale should be closed. In the mini-ECC group the venous cannulation is secured by a second snare around the atrial incision to ensure stabilization of the cannula and minimize air aspiration into the mini-ECC system. CPB was conducted in moderate hypothermia (32 °C). High-potassium cold blood cardioplegia was injected for 5 min in the aortic root immediately after cross clamping the aorta and repeated every 20—30 min in the CPB group. A 1-min warm reperfusion with 37 °C oxygenated blood with a flow rate of 200—300 ml/min was performed immediately after the last distal anastomosis while the mammary artery(ies) was unclamped. In the mini-ECC group, 100 ml of crystalloid cardioplegia was injected after cross clamping the aorta and repeated only if mechanical activity of the heart was observed, which was the case in three patients (5.5%). No warm reperfusion was done in this group. In both groups, proximal bypass grafts anastomoses to the ascending aorta were performed during rewarming. Priming volume of the CPB was 1800 ml and of the mini-ECC, 600 ml. The minimized cardiopulmonary bypass (MECC, Jostra AG, Hirrlingen, Germany) is driven by a centrifugal pump without cardiotomy reservoir. In our setting, air is detected by an ultrasound probe, placed at the highest level of the venous cannula. If air is detected within the mini-ECC, perfusion stops immediately. Up to now this system detected one air emboli in 520 patients operated with the mini-ECC system and removal of the air was successful. To prevent additional damage to the blood cells in the mini-ECC group a new suction device Cardiosmart® (Cardiosmart AG, Muri, Switzerland) was integrated into the system. Aspiration of blood is controlled by an optoelectrical sensor at the tip of the suction cannula and suction mechanism is started only when the tip of the suction cannula is in direct contact with the blood. The aspirated blood is directly retransfused into the venous line of the circuit and therefore no additional suction pump or reservoir is required. In the CPB group a classical suction unit was used, driven by a roller pump and the aspirated blood was forwarded to the cardiotomy reservoir.

2.3. Measurement of cardiac markers

Serial venous blood samples were taken preoperatively in both groups as well as after aortic unclamping at 6, 12, and 24 h. The cTnI concentration was analyzed by immunoassay using the Stratus II analyzer (Dade Behring). The upper limit of norm is 0.6 μg/l. Creatine kinase isoenzyme MB (CK-MB) was measured preoperatively and at 6, 12, and 24 h after unclamping the aorta. A 12-lead electrocardiogram (ECG) was recorded preoperatively and at 6 and 24 h after surgery. Patients with perioperative myocardial infarction (PMI) were excluded from the present study in order not to influence statistical analysis of myocardial markers between the two groups. Criteria used in the present study were new Q-waves of more than 0.04 ms and a reduction in R-waves of more than 25% in at least two leads in the ECG as well as echocardiographic criteria according to the guidelines reported by the STS. The CK-MB diagnosis criteria for PMI were CK-MB values of more than 60 IU/l at 6, 12 or 24 h postoperatively.

2.4. Statistical analysis

Data are presented as mean values ± their first standard deviation. A Mann—Whitney *U*-test and χ^2-test were used for comparison between groups of continuous and nominal variables, respectively. A *p*-value of less than 0.05 was considered significant.

3. Results

Fourteen patients (9.1%) had preoperative elevation of cTnI-values and were excluded from the present study. Additional four patients were excluded because of a PMI, according to the criteria described above, two patients from each group. Therefore, the analyzed collective contains 136 patients (100%) of whom 82 (60.3%) underwent surgery with CPB and 54 (39.7%) with mini-ECC. No patient died during the postoperative period.

Average age was 67.5 ± 8.5 years in the CPB group versus 66.0 ± 10.1 years in the mini-ECC group (p = ns). Preoperative characteristics were similar in both groups. Average EuroSCORE was 4.4 ± 1.2 in the CPB group and 4.7 ± 1.8 in the mini-ECC group (p = ns) (Table 1). Average extracorporeal circulation (ECC) time was 68.6 ± 24.1 min in the mini-ECC group and 84.1 ± 29.6 min in the CPB group ($p = 0.06$) and aortic cross-clamping (ACC) time was shorter in the mini-ECC group with 41.9 ± 17.2 min versus 53.4 ± 21.6 min in the CPB group ($p = 0.07$). The number of distal anastomoses (3.2 ± 1.0 CPB vs 3.2 ± 0.9 mini-ECC; p = ns) and the type of grafts, used for myocardial revascularization, were similar in both groups.

The mini-ECC group showed significantly lower concentrations of cTnI 11.8 ± 11.6 μg/l versus 24.2 ± 26.0 μg/l ($p < 0.05$) in the CPB group 24 h postoperatively (Fig. 1). Duration of ventilation and length of stay in the ICU were shorter in the mini-ECC group ($p < 0.05$). The incidence of atrial fibrillation in the early postoperative period was markedly reduced in the mini-ECC group with an incidence of 7.4% versus 20.7% in the CPB group ($p < 0.05$). Length of stay was significantly shorter in the mini-ECC group with an average of 8.1 ± 2.7 days versus 9.3 ± 4.2 days in the CPB group ($p < 0.05$).

Table 1
Data of patients who underwent CABG surgery with conventional cardiopulmonary bypass (CCPB) (n = 82) and patients with minimal extracorporeal circulation (MECC) (n = 54)

	CCPB	MECC	p-value
Demographic			
Number of patients	82 (60.30%)	54 (39.70%)	
Mean age (years)	67.5 ± 8.5	66.0 ± 10.1	ns
Male	66 (80.50%)	42 (77.80%)	ns
Preoperative ejection fraction (%)	55.8 ± 14.5	58.6 ± 14.3	ns
EuroSCORE	4.4 ± 1.2	4.7 ± 1.8	ns
Intraoperative			
Number of distal anastomoses	3.2 ± 1.0	3.2 ± 0.9	ns
Duration of ECC (min)	84.1 ± 29.6	68.6 ± 24.1	ns
Duration of ACC (min)	53.4 ± 21.6	41.9 ± 17.2	ns
Postoperative			
Duration of ventilation (h)	16.7 ± 27.3	12.0 ± 4.0	<0.05
ICU stay (h)	30.1 ± 32.6	24.9 ± 7.3	<0.05
Requirement of volume −12 h (ml)	2350 ± 824	2675 ± 1039	ns
Diuresis −6 h (ml)	865 ± 422	609 ± 330	ns
Transfusion of EC (no. of patients)	26 (31.70%)	21 (38.90%)	ns
Average EC/patients	2.57	1.83	ns
Inotropic support (−6 h)	26 (31.70%)	18 (33.30%)	ns
Inotropic support (6—12 h)	17 (20.70%)	6 (11.10%)	<0.05
Atrial fibrillation	17 (20.70%)	4 (7.40%)	<0.05
Cerebrovascular accident	2 (2.40%)	0 (0%)	ns
Length of stay (days)	9.3 ± 4.2	8.1 ± 2.7	<0.05
Myocardial markers			
CK (6 h)	351 ± 153	343 ± 153	ns
CK (12 h)	547 ± 371	513 ± 501	ns
CK (24 h)	554 ± 290	640 ± 646	ns
CK-MB (6 h)	21.5 ± 13.3	15.5 ± 9.4	<0.05
CK-MB (12 h)	23.3 ± 15.0	15.8 ± 11.3	<0.05
CK-MB (24 h)	21.7 ± 13.2	17.4 ± 12.7	ns
cTnI (6 h)	18.2 ± 22.2	8.3 ± 5.8	<0.05
cTnI (12 h)	16.9 ± 14.6	10.5 ± 8.3	<0.05
cTnI (24 h)	24.2 ± 26.0	11.8 ± 11.6	<0.05

Patients with pre- or perioperative myocardial infarction haven been excluded. Data are displayed as absolute values or mean values (±1SD). ECC: extracorporeal circulation time; ACC: aortic cross-clamping time; ICU: intensive care unit; EC: erythrocyte concentrate (400 ml); CK: creatine kinase; CK-MB: creatine kinase isoenzyme MB; cTnI: cardiac Troponin-I.

4. Discussion

CABG with the help of CPB is an established and safe procedure; however, off-pump myocardial revascularization has gained increased popularity in the last decade. Nevertheless, despite some advantages, off-pump myocardial revascularization is considered controversial—mainly due to the less optimal operative field, which may result in incomplete or unsatisfactory procedures [10]. Technical refinements of CPB-circuits may partly counterbalance the negative aspects of CPB. Mini-ECC system, a minimalization of the CPB system, has the potential to reduce blood transfusion requirements and blood—air interactions. This system was developed and introduced successfully in clinical routine by the group of Regensburg [11]. In the setting and for the present purpose, the reduction in the priming volume observed with the mini-ECC system and the use of Cardiosmart® offer an excellent alternative to CPB. Distal anastomoses are performed on the arrested heart as in CPB and the number of distal anastomoses is not reduced due to technical limitations, when revascularization areas are difficult to expose due to hemodynamic instability. In our opinion mini-ECC is technically less demanding than OPCAB surgery and allows to maintain peripheral (cerebral) safe perfusion in contrast to a certain risk in off-pump procedures. Differences in ECC and ACC times are mainly due to the administration of cold blood cardioplegia in the CPB group for 5 min after clamping the aorta and repeated for 2 min every 20—30 min during cross clamping, while in mini-ECC patients a single shot is given, and therefore they do not reflect the complexity of distal anastomosis in the mini-ECC group. However, in mini-ECC the heart is not completely unloaded during the procedure and a persistent coronary flow is

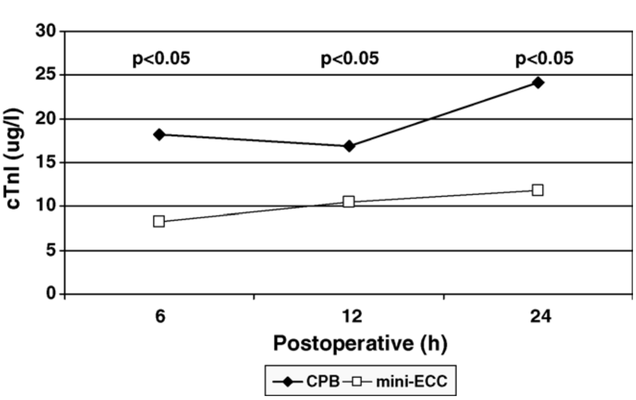

Fig. 1. Postoperative course of cTnI in patients being operated with CPB (n = 82) and mini-ECC (n = 54).

observed in a majority of patients, despite cross clamping the aorta, because there is no vent. This is the explanation for why distal anastomosis is more difficult in some patients. This minimal, residual perfusion of the arrested heart needs to be elucidated, but it could be one explanation for improved myocardial protection because it eliminates, practically, completely the presence of air in the coronary system. In our study cTnI-concentration and CK-MB-values in the mini-ECC group are on the level recently reported by Alwan et al. [9] in patients who underwent beating heart surgery. Our results are not influenced by the higher rate of perioperative defibrillation to restore sinus rhythm in patients operated with CPB as only minor or even no cTnI elevations have been reported after defibrillation [12,13]. Blood–air interaction is practically completely eliminated with the mini-ECC/Cardiosmart system. The venous reservoir is removed, the modified optoelectrical suction system prevents any air–blood contact and no vent is required on the ascending aorta. The improvement of myocardial protection may also be reflected in the fact that defibrillation to restore sinus rhythm (SR) after opening the aortic clamp was required only in one patient (1.9%) of the mini-ECC group, while spontaneous restoration of SR occurred in the others. In the CPB group, defibrillation was necessary in 38 patients (46.3%; $p < 0.05$). However, ventricular fibrillation can also be caused by air bubbles in the coronaries, reperfusion injury, and electrolyte disturbances. All these small advantages may be the explanation for earlier recovery and the observed reduction in the length of stay in the ICU and the overall hospitalization time. Overall requirement of blood transfusion was in favor of the mini-ECC group; however, transfusions in the CPB group were mainly performed during CPB because of the priming volume related to intraoperative hemodilution. During hospital stay, there was substantial reduction in atrial fibrillation, with an incidence of less than 10% in the mini-ECC group, without preoperative prophylactic medication. This might be due to a decrease in the usual volume shift observed in patients undergoing CPB and may be one aspect for the significant reduction in the length of stay observed in the mini-ECC group.

This is a prospective non-randomized protocol, which limits the power of this present study. However, similar results could be found in a smaller, randomized trial at our institution, including 40 patients prospectively randomized to either receive mini-ECC or CPB. In this collective similar results could be found, which may partly counterbalance this limitation.

We conclude that minimal cardiopulmonary bypass using the MECC® system with our technique of cardioplegic arrest is a safe procedure and seems to cause less damage to the myocardium than does conventional cardiopulmonary bypass. This is reflected by the lower release of cTnI in the mini-ECC group. One of the main advantages of the mini-ECC system is to maintain central and peripheral safe perfusion in contrast to the risk of hypoperfusion during OPCAB surgery. Earlier recovery and a significant lower incidence of postoperative atrial fibrillation are some additional benefits in patients being operated with the mini-ECC system.

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