Beating Heart Revascularization with Minimal Extracorporeal Circulation in Patients with a Poor Ejection Fraction

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ABSTRACT

Background: Coronary artery bypass grafting with cardioplegia in patients with a low ejection fraction carries a risk of myocardial ischemia. Beating heart surgery is associated with hemodynamic changes when the heart is manipulated. We assessed an alternative: minimal extracorporeal circulation for coronary artery bypass grafting on a beating heart in patients with a poor ejection fraction.

Methods: From January 2000 to January 2002, 50 patients with an ejection fraction of less than 35%, who represented 10% of all patients undergoing coronary artery procedures, underwent revascularization on a beating heart with assistance. We used a closed cardiopulmonary bypass system with a centrifugal pump without reservoir, and the surgical strategy was modified to avoid aortic cross-clamping and to decrease bypass time.

Results: The main preoperative characteristics were: age (mean ± SD) of 64 ± 11.2 years (range, 41-87 years), 35 male patients (70%), mean left ejection fraction of 24.8% ± 11.2%, and a mean EuroSCORE of 5.8 ± 2.7. Revascularizations of 146 distal anastomoses (2.9 ± 0.7 grafts/patient) were completed. Twelve percent were double bypass, 86% were triple bypasses, and 2% were quadruple bypasses; the mean bypass time was 64.2 ± 26.2 minutes. The mean graft number was 2.9, and the hospital mortality was 2%. Perioperative hematocrit levels were 30.1%, and 26% of patients received transfusions. Postoperative data showed a median extubation time of 9 hours, a median intensive care unit stay of 48 hours, and a hospital stay of 8 ± 2 days. Postoperative complications included inotropic support (14%), cerebrovascular events (2%), reoperation for homeostasis (4%), delayed sternal closure (2%), and mediastinitis (2%). Peak troponin Ic level remained a low 2.4 ± 1.9 µg/mL. Follow-up at 6 months was complete with 1 late mortality and with a mean ejection fraction of 30.5% ± 10.8% for the survivors.

Conclusions: Coronary revascularization on a beating heart with extracorporeal assistance can be done in patients with a low ejection fraction. It avoids the myocardial injury associated with aortic cross-clamping and allows safe and complete coronary revascularization.

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INTRODUCTION

Cardiopulmonary bypass (CPB) with aortic cross-clamping and cardioplegic arrest remains the gold standard but is associated with several effects related to aortic cross-clamping and CPB, which are of concern in certain high-risk patients [Hammermeister 1990], because these techniques are associated with a multitude of pathogenic mechanisms responsible for postoperative morbidity [Hammerschmidt 1981, Kirklin 1991]. The risk factors are increasing steadily as we are presented with older, sicker patients. Off-pump coronary artery bypass (OPCAB) has been proposed to decrease the mortality and morbidity in high-risk [Bergsland 1997, Moshkovitz 1997, Arom 2000] and low-risk patients [Cartier 2000]. However, the most common procedure in most series of OPCAB has been the grafting of the left internal mammary artery to the left anterior descending artery via a sternotomy or a limited anterior thoracotomy [Calafiore 1998, Hart 2000]. OPCAB creates hemodynamic instability and reduces coronary artery blood flow [Gründeman 1998], mainly because of the extreme tilting of the heart during revascularization of the circumflex region [Gründeman 1997, Nierich 2000]. Because OPCAB is also technically more demanding, some concerns have been raised about the quality of the anastomosis and its long-term patency [Pagni 1997]. Others have described coronary artery bypass grafting (CABG) on a beating heart with the use of an axial blood flow pump [Sweeney 1992, Lönn 1999]. These techniques offer the advantage of performing CABG without the risk of CPB. However, despite allowing multiple revascularizations, CABG remains a difficult procedure for reaching the marginal branches of the circumflex artery [Lönn 1999]. In addition, if instability does occur, it is generally linked to right heart failure, which cannot be assisted with this technique. To decrease the mortality and the morbidity in this population of patients with a low ejection fraction, the surgeon has to modify the CPB and should avoid aortic cross-clamping. Our concept involves a modification of both the bypass circuit and the surgical technique. We relate our experience with a prospective study using a minimal extracorporeal circulation (MECC) to perform surgical revascularization on a beating heart and without aortic cross-clamping.

MATERIALS AND METHODS

From January 2000 to January 2002, 480 patients underwent CABG in our institution. Three hundred seventy-four patients (78%) underwent CABG with cardioplegia, 56 patients (12%) underwent off-pump revascularization, and 50 patients (10%) with an ejection fraction of less than 35% underwent CABG on a beating heart with assistance. Patients included for CABG on a beating heart with assistance were those with multivessel disease involving the circumflex artery with an ejection fraction of less than 35% and not amenable for angioplasty. Patients receiving operations included emergency cases and those in cardiogenic shock. Excluded patients were those with single or double coronary artery lesions of the anterior left ventricle or of the right heart, which were treated with procedures performed off pump, and patients who had undergone redo coronary surgery.

All patients were treated according to our routines for preoperative and postoperative care. The patients were mechanically ventilated with a mixture of oxygen and air (Servo Ventilator 900; Siemens, Saint-Denis, France), and anesthesia was maintained with sufentanil (Sufenta), midazolam (Hypnovel), and pancuronium bromide (Pavulon). Placement of a central venous pressure line allowed continuous hemodynamic monitoring and mixed venous oxygen saturation. A midline sternotomy was performed.

The MECC system consists of a centrifugal pump head (MECC system; Jostra, Hirrlingen, Germany), an integrated heat exchanger–oxygenator, an arteriovenous loop (Jostra Bioline coating system), a priming and recirculation line, a pressure and sampling port, an arterial and 2-stage venous cannula, and 500 mL of priming solution. We do not use a left ventricular vent, cardiotomy suction, or a venous reservoir.

Before performing the proximal anastomoses, the surgeon administered heparin (250 U/kg) to the patient directly into the atrium. After dissection of the saphenous vein and/or mammary artery, the proximal anastomoses were done under partial aortic cross-clamping. Additional heparin doses were given before starting the system and were guided by an activated clotting time of not less than 400 seconds. All procedures were performed at normothermia. The MECC system was placed as close as possible to the patient at the right side of the chest. Ventilation was maintained throughout the procedure when the heart was beating. CPB was started by raising the circuit pressure above the patient's systemic pressure, and we either maintained the patient on partial cardiopulmonary support or progressively reached the total calculated flow (2.2 L/m^2) when necessary. In all cases, we maintained a mean blood pressure above 70 mm Hg. During bypass, we monitored hematocrit, activated clotting time, line pressure, blood gases, and the patient's parameter values (arterial blood pressure, central venous pressure, temperature, and diuresis). Revascularization was done sequentially, starting with the most ischemic zone and ending with the left mammary artery on the left anterior descending artery. Once all anastomoses were completed, the simplified bypass system was slowly stopped while the patient's filling and systemic pressures were optimized. All aspirated blood, as well as the complete contents of the arterial and venous lines, was returned to the patient by means of a cell saver.

All distal vessel anastomoses were done on a beating heart. Our technique of distal anastomosis on a beating heart involved the help of a cardiac stabilizer. Briefly, to obtain hemostasis, 2 vessel loops were placed on either side of the vessel to be bypassed. We used intraluminal coronary shunts (flow-through; Bio-Vascular, St. Paul, MN, USA) during the suturing of the distal anastomosis if any dysrhythmia or ischemia was detected on the electrocardiogram. Before tying the suture of the distal anastomosis, we released the coronary shunts and/or the vessel loops to verify proximal, distal, and conduit flow. We believe this step avoids a purse-string effect on the distal anastomosis. Proximal and distal anastomoses were carried out with a running 7-0 or 8-0 Prolene suture (Ethicon, Somerville, NJ, USA). As soon as the distal anastomoses were completed, flow to the native coronary artery was established to perfuse the revascularized region while the patient was on bypass. For all patients, we recorded preoperative variables (see "Appendix") to calculate a European score [Nashef 1999]. Hemodynamic recordings were made during CPB. Blood chemistry data were obtained the day before the operation and on subsequent postoperative days. To determine heart muscle damage, we measured the enzyme troponin Ic postoperatively in the intensive care unit at 24 and 48 hours. Short-term follow-up (6 months) was completed for all patients and was performed by consulting the referring physician. All patients underwent preoperative and postoperative transthoracic echocardiography with measurement of ejection fraction by viewing 2 and 4 apical chambers with modified Simpson methods.

Statistics

For statistical nomenclature and data analysis we followed the "Guidelines for Data Reporting and Nomenclature" published in the *Annals of Thoracic Surgery*. Descriptive statistics were used to summarize the data in terms of mean, median, SD, and range.

Patient Population

Demographic and preoperative data are shown in Table 1. Seven patients (14%) were in cardiogenic shock when they underwent operations. Six patients had an intra-aortic balloon pump placed prior to surgery and required inotropic support. One patient with an ejection fraction of 20% was in cardiac arrest after a failed angioplasty and was immediately placed on cardiac support. He underwent a single saphenous vein graft to the left anterior descending artery and was weaned off CPB on a low dose of dobutamine.

RESULTS

In-Hospital Outcome

Intraoperative data are listed in Table 2. Revascularization was as complete as possible with 146 distal anastomosis

Table 1. Preoperative Data*

No. of patients	50
Age, y	64 ± 11.2 (range, 41-87)
Body surface area, m^2	1.8 ± 0.1
Men, n (%)	35 (70)
NYHA class, n (%)	
I	7 (15)
II	13 (27)
III	6 (9)
IV	24 (48)
Unstable angina, n (%)	29 (58)
Myocardial infarction <7 days, n (%)	14 (28)
Cardiogenic shock, n (%)	7 (14)
Preoperative left EF, %	24.8 ± 11.2
EuroSCORE	5.8 ± 2.7

*Data are presented as the mean ± SD as indicated. NYHA indicates New York Heart Association; EF, ejection fraction; EuroSCORE, European System for Cardiac Operative Risk Evaluation.

Table 2. Intraoperative Data*

No. of patients	50
No. of grafts/patient	2.9 ± 0.7 (range, 2-4)
Arteries bypassed, n	146
Left anterior descending, n (%)	50 (100)
Diagonal, n (%)	12 (24)
Marginal branches of circumflex, n (%)	48 (96)
Right coronary, n (%)	36 (72)
Double bypass, n (%)	6 (12)
Triple bypass, n (%)	43 (86)
Quadruple bypass, n (%)	1 (2)
Bypass time, min	64.2 ± 26.2
Flow, L/min	2.7 ± 1.1

*Data are presented as the mean ± SD as indicated.

performed, and the mean number of distal grafts per patient was 2.9 ± 0.7 (range, 2-4). The bypass system allowed either complete cardiopulmonary support or partial support, and the mean bypass flow was 2.5 ± 0.9 L/min (range, 0.5-5.3 L/min) for a mean body surface area of 1.82 ± 0.1 m^2. The mean bypass time was 64.2 ± 26.2 minutes.

The mean venous pressure recorded during the procedure was 4.5 ± 2.8 mm Hg, and arterial and venous blood gas concentrations monitored throughout the procedure remained within normal ranges. The total priming volume was 500 mL, which allowed the intraoperative hematocrit level to remain elevated at 30.1% ± 4.9%, with 13 patients (26%) receiving transfusions. Several complications occurred in 9 (18%) of the patients (Table 3): reoperation for delayed sternal closure occurred 1 patient (2%); inotropic support, in 6 patients (12%); increased ventilation greater than 48 hours, in 6 patients (12%); mediastinitis, in 1 patient (2%); nonreversible neurologic event, in 1 patient (2%); and lower gastrointestinal tract bleeding, in 1 patient (2%).

Mean hospital stay was 8 ± 2 days with a mean intensive care unit stay of 2 days. The level of troponin Ic, a more sensitive marker of heart muscle ischemia during operation, remained low at 2.4 ± 1.9 μg/L (normal values at our institution are less than 5 μg/L).

Before discharge, 2 patients underwent postoperative angiography because of angina. In one patient a small posterior descending artery was dilated, and in the other patient, who had previously undergone a left pneumonectomy and irradiation, the left main artery was dilated. All grafts and anastomoses were patent.

Six-Month Follow-up

All patients were available for follow-up. At 6 months, 1 death occurred in a patient with prior left main disease that had been treated with 2 grafts (left anterior descending and diagonal). The circumflex region could not be revascularized because of severe epicardial fibrosis from prior irradiation. This patient underwent postoperative left main angioplasty and was discharged. Six months later, he complained of angina but refused another angiogram. Three weeks after that, the patient was admitted in cardiogenic shock at another hospital and could not be resuscitated. All patients underwent postoperative echography, which revealed an improvement in the mean ejection fraction (24.8% ± 11.2% versus 30.5% ± 10.8%; $P = .003$).

DISCUSSION

Myocardial revascularization has evolved in part from the techniques of angioplasty and stents and in part from surgical techniques involving the use of various arterial and venous conduits. Numerous studies have identified risk factors of mortality in coronary artery surgery [Hammermeister 1990, Grover 1994]. This risk has slowly decreased owing to improvements in surgical techniques and anesthesia management, which have therefore enabled physicians to calculate a predicted risk of

Table 3. Postoperative Results*

No. of patients	50
Ventilation time, h	9.2 ± 22.6
Inotropic support, n (%)†	7 (14)
Intra-aortic balloon, n (%)	5 (10)
Cerebrovascular event, n (%)	1 (2)
Reoperation for homeostasis, n (%)	2 (4)
Mediastinitis, n (%)	1 (2)
Bleeding in first 24 hr, mL	614 ± 212
Troponin Ic, μg/L	2.4 ± 1.9
Intensive care unit stay, d	2.6 ± 6.9
Hospital stay, d	9.4 ± 5.8
Hospital mortality, n (%)	1 (2)
Postoperative transfusion, n (%)‡	15 (31)
Preoperative hematocrit, %	34.7 ± 5.1
Postoperative hematocrit, %	30.1 ± 4.9

*Data are presented as the mean ± SD as indicated.
†Including dobutamine, dopamine, and noradrenaline.
‡All homologous transfusions.

mortality for each patient [Nashef 1999]. Low ejection fraction remains a major risk factor of mortality following coronary artery revascularization, and this fact is witnessed by the increased mortality observed in this surgical population.

For some of these high-risk patients, undergoing OPCAB may decrease postoperative morbidity and mortality [Ascione 1999, Arom 2000, Ricci 2000]. However, this initial advantage with OPCAB has to be carefully evaluated with the long-term results that have shown a higher rate of reoperation in patients receiving OPCAB than in those undergoing CPB in cases of acute myocardial infarction [Locker 2000] and left ventricular dysfunction [Sternick 2000]. The results in these studies and others [Gundry 1998] can be related to the incomplete revascularization performed with OPCAB. This finding is witnessed by the decreased number of marginal bypass grafts performed in the series conducted with beating heart compared with series performed with cardioplegia. This result is in part due to the difficulty of performing distal anastomoses on the circumflex branches via a sternotomy. This difficulty has been well demonstrated in numerous animal [Gründeman 1998] and clinical studies [Nierich 2000], because the tilting of the heart reduces venous returns and decreases cardiac output. This effect can partly be compensated in patients with so-called good ventricles by raising the preload (via the Trendelenburg position and fluid administration) and/or the adjunct of inotopic support during the completion of the anastomosis. However, raising the preload is poorly tolerated in patients with a poor ejection fraction and a dilated heart with no reserve, because raising the preload is usually followed rapidly by heart failure. Therefore, our surgical approach for these patients was based on 2 main objectives: first, we tried to use CPB and aortic cross-clamping for as little time as possible to decrease myocardial ischemia; and, second, to compensate for the decrease in cardiac output that occurred during completion of the distal anastomosis, we used CPB as an assistance to maintain stable hemodynamic conditions. With the MECC system, access to all coronary arteries, including the marginal branches, was no longer a problem. The CPB compensates for the decrease in cardiac output, and coronary perfusion is maintained throughout the entire surgery because an aortic systolo-diastolic pressure is obtained. Hemodynamic conditions were stable throughout the operation in our patients, as witnessed by the various hemodynamic and biological parameters studied, and electrocardiography results and the low postoperative levels of troponin indicated no signs of ischemia. In addition, if stabilization is not optimal for performing an anastomosis of good quality, cardioplegia can easily be given to permit the revascularization of the difficult region, followed or preceded by revascularization of the other regions with the aorta unclamped to decrease aortic cross-clamping.

In our practice, to further decrease the mortality and morbidity related to surgical revascularization, we apply CABG on a beating heart with MECC as a method of revascularization for high-risk patients with multivessel disease. Numerous co–risk factors, such as urgency, cardiogenic shock, complications from angioplasty, and recent myocardial infarctions, did not appear as risk factors with this technique. The postoperative course was markedly simplified, because few patients presented a low cardiac output. One benefit of the MECC was the reduction in priming and thus a greater hematocrit volume with this technique compared with standard extracorporeal circulation. This technique is probably beneficial for older and arteritic patients who do not tolerate hemodilution well. This study of surgical revascularization compares favorably with the in-hospital mortality rate of 1% reported in the AWESOME trial of percutaneous revascularization in high-risk patients [Morrison 2001], with the advantage of permitting complete revascularization.

We think that this procedure involving the beating heart with hemodynamic assistance is most beneficial for candidates with impaired left ventricular function or acute ongoing ischemia, because myocardial ischemia is reduced with this technique. The potential benefits of an MECC are the avoidance of hemodilution and maintenance of coronary perfusion and systemic systolo-diastolic pressure during CPB. The results of this study need to be confirmed by other larger, long-term studies.

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APPENDIX

European System for Cardiac Operative Risk Evaluation (EuroSCORE)

Risk Factors	Definition	Score
Patient-related factors		
Age	1 point per 5 years more than 60 years	1
Sex	Female	1
Chronic pulmonary disease	Long-term use of bronchodilatators or steroids for lung disease	1
Extracardiac arteriopathy	Any one or more of the following: claudication, carotid occlusion or >50% stenosis, previous or planned intervention on the abdominal aorta, limb arteries, or carotid arteries	2
Neurologic dysfunction	Disease severely affecting ambulation or day-to-day functioning	2
Previous cardiac surgery	Required opening of the pericardium	3
Serum creatinine level	>200 μmol/L preoperatively	2
Active endocarditis	Patient still under antibiotic treatment for endocarditis at the time of surgery	3
Critical preoperative state	Any one or more of the following: ventricular tachycardia or fibrillation or aborted sudden death, preoperative cardiac massage, preoperative ventilation before arrival in the anaesthetic room, preoperative inotropic support, intra-aortic balloon counterpulsation, or preoperative acute renal failure (anuria or oliguria <10 mL/h)	3
Cardiac-related factors		
Unstable angina	Rest angina requiring intravenous nitrates until arrival in the anaesthetic room	2
Left ventricular dysfunction	Moderate or left ventricular ejection fraction of 30% to 50%	1
	Poor or left ventricular ejection fraction <30%	3
Recent myocardial infarct	<90 days	2
Pulmonary hypertension	Systolic pulmonary artery pressure >60 mm Hg	2
Operation-related factors		
Emergency	Carried out on referral before the beginning of the next working day	2
Other than isolated coronary artery bypass graft	Major cardiac procedure other than or in addition to coronary artery bypass graft	2
Surgery on thoracic aorta	For disorder of ascending arch or descending aorta	3
Postinfarct septal rupture		4