Original Article

Application of Off-pump Coronary Artery Bypass Grafting for Patients with Acute Coronary Syndrome Requiring Emergency Surgery

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Off-pump coronary artery bypass grafting (OPCAB) has become a more applicable procedure, even in patients with multi-vessel disease. However, the role of OPCAB for patients with acute coronary syndrome (ACS) requiring emergency revascularization has not been established yet. We reviewed our results of emergency coronary artery bypass grafting (CABG) for patients with ACS. Seventy-two patients with ACS who underwent emergency CABG were studied. Twenty-five underwent OPCAB and 47 on-pump CABG. OPCAB was mainly indicated for patients who were possibly at risk for cardiopulmonary bypass. When the coronary anatomy was suitable in younger or less risky patients, OPCAB was performed. Patients with multi-vessel disease or with a critical left main trunk lesion were not excluded from OPCAB. The mean number of grafted vessels was 2.6 per patient in the OPCAB group, and 3.8 per patient in the on-pump group ($p<0.0001$). However, none of the patients in either group required postoperative catheter intervention. Mean operative time was 195 minutes in the OPCAB group and 286 minutes in the on-pump group ($p<0.0001$). There were three postoperative deaths in the OPCAB group and four in the on-pump group. Multivariate logistic regression analysis revealed that preoperative cardiogenic shock was the only significant predictor for postoperative death (odds ratio, 7.33). The selection of the on-pump procedure or OPCAB did not correlate with operative death. Thus, we conclude that OPCAB can be performed safely and effectively in selected patients with ACS requiring emergency coronary revascularization. (Ann Thorac Cardiovasc Surg 2003; 9: 29–35)

Key words: off-pump coronary artery bypass grafting (OPCAB), minimally invasive surgery, acute coronary syndrome (ACS)

Introduction

The benefits of coronary revascularization without the influence of cardiopulmonary bypass have made off-pump coronary artery bypass grafting (off-pump CABG, OPCAB) a widely acceptable procedure. Despite its technically demanding characteristics, the recent advancement in technology and accumulation of experience have paved the way to a more complex coronary revascularization with OPCAB. Complete revascularization can be achieved with this technique even in patients with multi-vessel coronary disease.[1-3)]

Patients who suffer from unstable angina or acute myocardial infarction often need to undergo percutaneous catheter intervention (PCI) or CABG to relieve their symptoms on an emergency basis. Under these circumstances, patients are more likely to have risks that lead to postoperative morbidities than when the surgery is elective. Even if a patient is a poor risk for cardiopulmonary bypass (CPB), he or she has to undergo CABG to survive.

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Although favorable results have been reported with the conventional on-pump technique,[4-6] several problems remain to be solved to obtain better results.

Since 1999, we have been performing the OPCAB procedure in an emergency situation to reduce postoperative morbidities in managing these high-risk patients. However, the exact role of OPCAB for patients with acute coronary syndrome (ACS) who are in a critical condition requiring emergency CABG has not been established yet.

This study was designed to clarify the feasibility of OPCAB in emergency coronary bypass surgery by reviewing our results of emergency CABG for patients with ACS.

Patients and Methods

From January 1998 to December 2001, 72 patients with ACS who underwent emergency CABG within 24 hours after admission to the coronary care unit (CCU) at our institute were studied. They included 47 male and 25 female patients. Their age ranged from 32 to 86 years with a mean of 67.2 years. Forty-three patients were diabetic, of whom only three were insulin-dependent, and 48 were hypertensive. Eleven patients had impaired renal function (serum creatinine>3 mg/dl), and eight had a previous history of cerebrovascular accident. Acute myocardial infarction (AMI) was complicated in 44 patients. Intra-aortic balloon pumping (IABP) was activated in 49 patients. Twenty-one patients were under respiratory support. Fourteen patients were in cardiogenic shock (systolic blood pressure<90 mmHg; cardiac index<2 L/m^2; necessitating aggressive inotropic support and IABP). Of these, 47 patients underwent on-pump CABG and 25 OPCAB.

Preoperative variables of both OPCAB and on-pump CABG groups are shown in Table 1.

Patient selection

Our patient selection criteria regarding the two procedures, on-pump CABG or OPCAB were as follows: younger patients (<60 years) with multi-vessel disease with minimal risks for CPB underwent on-pump CABG. In addition, when possible difficulties with revascularization with OPCAB were anticipated, on-pump CABG was selected. These conditions included poor quality of the coronary arteries, such as calcification or diffuse atherosclerotic narrowing on the angiogram or hemodynamic instability of the patient, e.g. cardiogenic shock requiring inotropics and/or IABP support or the appearance of fatal ventricular arrhythmias.

OPCAB was indicated for patients who were possibly at risk for CPB, i.e., those who were elderly (>75 years old), who had a history of cerebrovascular disease, or whose renal function was compromised (serum creatinine>3 mg/dl). When the coronary anatomy was suitable for OPCAB, even in younger or less risky patients, OPCAB was indicated. As mentioned above, hemodynamic instability itself was considered to be a contraindication for OPCAB. However, once the hemodynamic condition was stabilized with the use of IABP and inotropics, OPCAB was performed in the patient.

Multi-vessel disease or a critical left main trunk (LMT) lesion (>90%) in a patient was not considered as contraindication for OPCAB.

Operative technique

Anesthesia was induced with midazolam at 0.1 to 0.2 mg/kg, vecuronium bromide at 0.1 mg/kg, and fentanyl at 3 to 5 μg/kg and was maintained by inhalation of 1-2% of sevoflurane with an air-oxygen mixture.

To maintain hemodynamic and electrocardiographic stability, IABP support or inotropic administration was started whenever required. Diltiazem, nicorandil and isosorbide dinitrate were administered throughout the operation. Anticoagulation was achieved with heparin at 150 U/kg for OPCAB and 200 U/kg for on-pump CABG after all grafts were harvested for coronary revascularization.

Transesophageal echocardiography was used for additional monitoring in all cases.

In the on-pump CABG, normothermic CPB was initiated and maintained in the usual manner. Cardioplegic arrest was established by cross-clamping the ascending aorta followed by an infusion of St. Thomas' solution from the aortic root and the coronary sinus (5 ml/kg) with replenishment of the solution mixed with the same dose of cold blood every 30 minutes (3 ml/kg). All the coronary revascularization procedures were performed during a single aortic cross-clamp period.

Surgical technique of OPCAB

In the OPCAB, perfusionist standby was available for all patients. Blood pressure was optimized carefully during the procedure with the selective use of vasoconstrictors. Sternotomy was employed in all patients.

In addition to left-sided deep pericardial retraction sutures and table rotation, we always placed a right vertical pericardiotomy on the right-sided diaphragmatic surface

Table 1. Preoperative variables in both groups

	OPCAB (n=25)	On-pump (n=47)	p value
Gender (M/F)	14/11	33/14	0.3
Age	73.9 (51-86)	66.3 (32-84)	0.005
Diabetes	13	30	0.45
Hypertension	13	35	0.069
Smoking	4	21	0.019
Obesity	3	13	0.15
Renal dysfunction	7	4	0.041
Cerebrovascular disease	6	2	0.018
AMI	16	28	0.8
OMI	4	18	0.063
IABP	19	30	0.426
Respirator	10	11	0.177
Cardiogenic shock	3	11	0.352
Vessels involved	2.52	2.77	0.031
LMT>75%	13	20	0.467
Prior PCI	5	6	0.497
Prior CABG	0	0	

AMI, acute myocardial infarction; OMI, old myocardial infarction; IABP, intra-aortic balloon pumping; LMT, left main trunk; PCI, percutaneous catheter intervention

toward the inferior vena cava to enter the right pleural cavity. This procedure facilitates exposure of the circumflex artery without compromising the patient's hemodynamics.

Local stabilization of the coronary artery was achieved by a mechanical stabilizer (Immobilizer™; Genzyme Corp., Cambridge, MA, U.S.A.). Two silicon elastic tapes were passed underneath the coronary artery to control bleeding and obtain local stabilization. Revascularization was first performed on the LAD, if it contained a critical lesion. The coronary artery was occluded by tightening the silicon tapes, and an arteriotomy was made if the patient's condition was unchanged. In sequential grafting, the proximal anastomosis was constructed first so that the blood supply to the coronary artery could be established immediately after completion of the anastomosis. The inflow of the free grafts, e.g., a free ITA, radial artery or saphenous vein, was the pedicled ITA in most instances except for a few patients in whom saphenous veins were attached to the aorta.

We did not use an intracoronary shunt except for the proximal right coronary anastomosis, which is associated with more frequent and marked hemodynamic and electrocardiographic changes. An anastomosis was constructed with a 7-0 or 8-0 monofilament continuous suture.

Statistical analysis

Statistical analysis was performed using SPSS 11.0J (SPSS Inc., Chicago, IL). Comparisons between the two groups were performed using an unpaired Student's t test. The χ^2 test using the exact tests was used for comparison of categorical data. Multivariate logistic regression analysis for operative outcome was performed using the patient characteristics and the difference between surviving patients and those who died after the operation as independent variables. Logistic regression analysis was performed choosing the forward-stepping selection method with maximum-likelihood estimates and default criteria. All p values were two-tailed, and a p value of less than 0.05 was considered significant.

Results

Operative variables of both OPCAB and on-pump CABG groups are shown in Table 2.

None of the OPCAB patients were converted to on-pump CABG. One patient, who was in profound cardiogenic shock and under percutaneous cardiopulmonary support, underwent CABG on the beating heart and was categorized in the on-pump CABG group.

The number of grafted vessels was 2.6 per patient in

Table 2. Operative results

	OPCAB (n=25)	On-pump (n=47)	p value
Grafted vessels	2.6	3.8	<0.0001
LITA	23	45	0.334
RITA	15	25	0.626
GEA	2	9	0.309
RA	7	11	0.777
SVG	12	25	0.805
Operative time (min)	195	286	<0.0001
Major complications	2	6	0.705
Perioperative MI	0	0	
Postoperative PCI	0	0	
Operative death	3	4	0.69

GEA, right gastroepiploic artery; RA, radial artery; SV, saphenous vein graft; MI, myocardial infarction

the OPCAB group and 3.8 per patient in the on-pump CABG group with a significant difference (p<0.0001). None of the patients in either group, however, required postoperative PCI.

The left internal thoracic artery (LITA) was used in 23 (92%) of the OPCAB patients and in 45 (96%) of the on-pump patients (p=0.334). The right internal thoracic artery (RITA) was used in 15 (60%) of the OPCAB patients and in 25 (53%) of the on-pump patients (p=0.626). Other arterial grafts were also used whenever required in both groups with no significant difference.

The number of bypass grafts of the OPCAB patients ranged from 1 to 5. In addition to the LAD and the diagonal branch, branches of the circumflex artery as well as the distal branches of the right coronary artery were successfully grafted in more than 20 patients (Table 3).

The mean operative time of the OPCAB patients was 195 minutes and was significantly shorter than in the on-pump patients (286 minutes, p<0.0001).

Major postoperative complications occurred in six patients in the on-pump group and two patients in the OPCAB group. They included respiratory failure (one in on-pump, one in OPCAB), sepsis (one in on-pump, one in OPCAB), consciousness disturbance (two in on-pump) or sternal dehiscence (two in on-pump). The two on-pump patients with consciousness disturbance recovered fully without neurological deficit by the time of discharge. Postoperative respiratory failure in an OPCAB patient resulted from pre-existing pneumonia. The patient died three weeks postoperatively. Another OPCAB patient who suffered from sepsis also died on the 17th postoperative day. IABP insertion seemed to have been the main cause of infection.

Perioperative myocardial infarction was not identified in any patient in either group.

The number of deaths within 30 days postoperatively was three in the OPCAB group and four in the on-pump group with no significant difference.

At univariate analysis (Table 4), patient age, preoperative respiratory support and cardiogenic shock were significant predictors for postoperative death. As with the other variables, selection of procedure, on-pump or OPCAB, was not correlated with postoperative death. At multivariate analysis, however, preoperative cardiogenic shock was the only predictor of operative death (p=0.017; odds ratio, 7.33; 95% CI, 1.42 to 37.86).

In the OPCAB patients, angiographic examination was performed in 12 patients within a month postoperatively. The patency rate was 12/12 for LITA, 7/7 for RITA, 2/2 for RA and 5/5 for SVG, whereas thinning of the ITA due to flow competition was observed in two patients.

Comment

Since the technique of CABG on the beating heart without CPB emerged,[7] great efforts have been made to establish this procedure as a standard one. In the early phase of OPCAB, only LITA-LAD anastomosis was constructed, through a small left anterior thoracotomy.[8] At the present time, however, multiple grafting through a

Table 3. Grafted vessels in the OPCAB group

No. of bypass	No. of patients	Grafted vessels			
		LAD	Dx	Cx	RCA
1	4	3			1
2	6	5	2	2	3*
3	13	13	10	8	7*
4	1	1	2	1	
5	1	1	1	2	1*

*: distal RCA
LAD, left anterior descending artery; Dx, diagonal branch; Cx, circumflex artery; RCA, right coronary artery

Table 4. Univariate analysis of survival and death

	Survival (n=65)	Death (n=7)	p value
Male/female	44/21	3/4	0.227
Age	68.0	77.9	0.026
Diabetes	37	6	0.23
Renal dysfunction	9	2	0.585
Cerebral vasculopathy	8	0	0.593
Preop. IABP	43	6	0.418
Respirator	16	5	0.02
Cardiogenic shock	10	4	0.023
AMI	39	5	0.70
Vessels involved	2.66	2.86	0.416
LMT	28	5	0.235
Comorbidities	4	1	0.41
No.of grafts	3.4	3.1	0.637
Op. time (min)	254	257	0.905
On-pump/OPCAB	43/22	4/3	0.688

sternotomy is often being performed. Branches of the circumflex artery and the distal branches of the right coronary artery are the targeted vessels to be approached without compromising the hemodynamics. With the advancement in technology and the accumulation of experiences among surgeons, however, these vessels can now be exposed safely and multiple revascularization can be achieved for patients with multi-vessel coronary disease.[1-3)]

In the emergency situation, elderly patients who exhibit more comorbidities and more advanced coronary artery disease had often been treated medically with or without PCI even if they needed to undergo CABG to survive. The adverse effects of CPB, such as systemic inflammatory response caused by the extracorporeal circulation or cerebrovascular emboli due to aortic cannulation can cause various postoperative morbidities.[9-11)] To overcome this dilemma, we adopted the OPCAB procedure for these high-risk patients requiring emergency CABG. Reflecting our patient selection criteria, the OPCAB patients in this series were significantly older and had a higher incidence of comorbidities than the on-pump patients.

The results of this study clearly show that the OPCAB procedure is not associated with increased mortality. The incidence of major postoperative complications was 8% (2/25) in the OPCAB group and 12.8% (6/47) in the on-pump group, although with no statistical significance. Furthermore, the operative time was significantly shorter in the OPCAB group than in the on-pump group (195 min versus 286 min, $p<0.0001$). Reduced operative time may have had a favorable influence, especially in the debilitated, elderly patients.

In this series, the mean number of grafted vessels in the OPCAB patients was 2.6 per patient, which was sig-

Table 5. Operative death patients

Pt.	Age	M/F	Preoperative condition					No. of grafts	Causes of death
			Respirator	AMI	OMI	Shock	LMT		
On-pump									
1	71	F	(+)	(+)				3	Sepsis, renal failure
2	76	M	(+)		(+)	(+)		5	VT, renal failure
3	84	M	(+)	(+)		(+)	(+)	3	LOS
4	77	F	(+)	(+)	(+)	(+)*	(+)	4	LOS
OPCAB									
1	78	F	(+)		(+)		(+)	2	Pneumonia
2	79	M		(+)	(+)		(+)	2	Sepsis, MOF
3	80	F	(+)	(+)		(+)	(+)	3	MOF

*: percutaneous cardiopulmonary support
M, male; F, female; CHF, congestive heart failure; VT, ventricular tachycardia; LOS, low-output syndrome; MOF, multiple organ failure

nificantly smaller than that in the on-pump patients (3.8 per patient). These figures were mainly due to our patient selection criteria. In addition, in the initial period of this series, we selected patients for OPCAB who needed fewer grafts to avoid incomplete revascularization. However, our accumulated experience has shown that all coronary arteries that need grafts can be steadily revascularized with OPCAB. Given this situation, our patient selection criteria have been changing to a more aggressive application of OPCAB for the ACS patients.

We do not consider the interval between the onset of AMI and the operation as crucial regardless of the revascularization procedure. In general, the optimal timing to perform an operation is whenever the ischemic myocardium needs to be revascularized.[4] Furthermore, we do not exclude a patient with a critical LMT lesion as a candidate for OPCAB. When a patient has an LMT lesion, the cardiologists in the CCU apply an IABP without exception. This can steadily stabilize myocardial ischemia as well as the hemodynamic condition throughout the operation, thus making OPCAB much safer.

There were seven postoperative deaths in this series, four in the on-pump and three in the OPCAB groups (Table 5). Multivariate logistic regression analysis showed that the single predictor of operative death was preoperative cardiogenic shock (3/4 in on-pump, 1/3 in OPCAB). Operative procedure, on-pump or off-pump, did not correlate with postoperative death.

Three patients (two in on-pump, one in OPCAB) had been in cardiogenic shock due to LMT occlusion preoperatively, i.e., left main shock syndrome.[12] Great efforts have been made to overcome this serious condition.[13-16] However, the mortality of patients with cardiogenic shock due to extensive myocardial damage is still high.[12,17] So far, the only solution for this problem may be close collaboration between cardiologists and cardiac surgeons with the aggressive use of percutaneous cardiopulmonary support (PCPS)[15,16] to maintain the patients' hemodynamic condition as stable as possible before surgery. Once surgery becomes a possible option, revascularization on a beating heart under PCPS or conventional CPB support without cardioplegic arrest may be an effective measure for these patients.

In conclusion, although our results failed to show clearly the advantage of OPCAB over on-pump CABG, OPCAB can be performed safely and efficiently in selected patients with ACS requiring emergency coronary revascularization. Patients with AMI or with a critical lesion in the LMT can be safely operated with OPCAB. Complete revascularization can be achieved with OPCAB even in patients with multi-vessel disease.

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