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Coronary Artery Bypass Grafting Without Cardiopulmonary Bypass: A five-year experience

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Abstract

The current drive to practice less invasive surgery is changing surgical practice towards safer and simpler procedures. The practice of coronary artery bypass grafting (CABG) on a beating heart without cardiopulmonary bypass (CPB), off-pump CABG or OPCAB, has been gaining great attention as an alternative approach to conventional CABG. Since the first adoption of OPCAB in 1997 at our department, 181 patients have undergone OPCAB. OPCAB was indicated for patients who were possibly at risk for CPB, i.e., those who were elderly, who had a history of cerebrovascular disease, whose ascending aorta was severely atherosclerotic with calcification, whose respiratory function was compromised, or whose renal function was compromised. A patient with a concomitant malignant neoplastic disorder was also a candidate for OPCAB because of the possible deleterious effect of CPB on the immune system. More recently, when the coronary anatomy was suitable for OPCAB, even in younger or less risky patients, OPCAB was indicated. The OPCAB procedure was performed through a median sternotomy in 146 patients (80.6%), a left thoracotomy in 27 (14.9%), a subxiphoid approach in 6 and a combined one in 2. One hundred and eleven patients (61.3%) received 1 or 2 grafts (Group I) and 70 (38.7%) received 3 or more grafts (Group II). The number of grafted vessels in Group II patients was 3 to 5 with a mean of 3.44. The mean operative time was 163 minutes in Group I and 209.5 minutes in Group II. The frequency of the use of arterial grafts such as LITA, RITA and RA was significantly higher in Group II than in Group I. Death occurred in 3 patients with acute coronary syndrome who had to undergo urgent surgery. Angiographic examination was performed within 3 months, postoperatively, in 98 patients (54.1%) revealing the overall patency rate of each graft: LITA 82/83 (98.8%), RITA 33/33 (100%), GEA 15/16 (93.8%), RA 20/20 (100%), and SVG 15/16 (93.8%).

We conclude that, in light of our 5-year experience, off-pump CABG on a beating heart can be safely and effectively performed, with acceptable angiographic results even in patients with multi-vessel coronary disease requiring multiple revascularization.

This procedure enables us to perform successful coronary bypass surgery for those who otherwise would not have been candidates for conventional CABG.

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Key words: coronary artery bypass grafting, minimally invasive surgery, off-pump CABG

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Introduction

After the first clinically successful coronary anastomosis using the saphenous vein was reported by Favalolo et al[1], widespread adoption of cardiopulmonary bypass (CPB) and cardioplegia greatly facilitated the coronary operation and provided the stimulus for a dramatic increase in the number of operations and the complexity of the procedure. The conventional coronary operation with CPB is both safe and effective. The pump oxygenator provides continuous systemic circulation, while cardioplegic arrest ensures myocardial protection and an accurate anastomosis in a quiet bloodless operative field. This method lends itself to complete myocardial revascularization with predictable long-term results, even in patients with severe triple-vessel disease.

The current drive toward less invasive surgery is changing clinical practice using safer and simpler procedure. Buffolo et al.[2] and Benetti et al.[3] independently reported large series performed by simple interruption of coronary flow. Postoperative angiographic studies showed no significant difference in graft patency between patients operated on with or without cardiopulmonary bypass. Their persuasive results led to renewed interest worldwide, and the practice of coronary artery bypass grafting (CABG) on a beating heart without cardiopulmonary bypass has been receiving great attention as an alternative approach to conventional CABG.

Since the first adoption of the off-pump CABG (OPCAB) in 1997, we have used the procedure on more than 200 cases. Our main concern has been to provide the patient with constant complete revascularization using the same conduits with an acceptable mortality and morbidity rate when compared to the on-pump CABG.

With growing surgical experience, our indication for OPCAB has been changing over the last few years and even a patient with multi-vessel disease requiring multiple grafts can now be a candidate for OPCAB. However, multi-vessel OPCAB has not gained popularity yet because of technical difficulties. This report aims at clarifying our 5-year experience of OPCAB by analyzing our results retrospectively.

Patients and Methods

From April 1997 to August 2002, 580 patients received an isolated CABG at our institute. Of these, 181 patients underwent OPCAB.

Patient selection for OPCAB

In the initial period of this series, we mainly performed LITA-LAD anastomosis through a small left anterior thoracotomy (MIDCAB) for patients who required a single-vessel revascularization. As mentioned above, the strategy has been changing along with the growing number of cases. Our current patient selection criteria regarding the two procedures, on-pump CABG or OPCAB are as follows: Younger patients (<60 yrs.) with multi-vessel disease with minimal risks for CPB are considered as candidates for on-pump CABG. In addition, when possible difficulties with revascularization with OPCAB are anticipated, on-pump CABG is selected. These conditions include poor quality of the coronary arteries, such as calcification or diffuse atherosclerotic narrowing on the angiogram or hemodynamic instability in a patient who needs an urgent operation, e.g., cardiogenic shock requiring inotropics and/or IABP support or the appearance of fatal ventricular arrhythmias.

OPCAB is indicated for patients who are possibly at risk for CPB, i.e., the elderly (>70 years old), who have a history of cerebrovascular disease and/or significant angiographic findings, whose ascending aorta is severely atherosclerotic with calcification, whose respiratory function is compromised (%VC< 60%), or whose renal function is compromised (serum creatinine>3 mg/d*l*). A patient who has a concomitant malignant neoplastic disorder is also a candidate for OPCAB because of the possible deleterious effect of CPB on the immune system[4,5]. When the coronary anatomy is suitable for OPCAB, even in younger or less risky patients, OPCAB is indicated. A critical left main trunk (LMT) lesion (> 90%) in a patient is not considered a contraindication

Table 1 Preoperative variables

	total	Group I (n = 111) *	Group II (n = 70) *:	p value
Gender	male 126	75	51	ns
	female 55	36	19	ns
Age	69.3 ± 8.1	68.3 ± 10.3	70.3 ± 8.8	ns
Diabetes	69	40	29	ns
Hyperlipidemia	79	50	29	ns
Hypertension	114	72	42	ns
Cerebrovascular disease	24	8 (7.2%)	16 (22.9%)	0.003
Renal dysfunction	27	18	9	ns
Angina status	stable: 144	96	48	
	unstable: 37	15 (13.5%)	22 (31.4%)	0.005
OMI	74	49	25	ns
AMI	23	12	11	ns
Prior PCI	33	20	13	ns
Prior CABG	12	12	0	0.004
LVEF (%)	54.8 ± 12.6	55.1 ± 14.2	54.4 ± 14.7	ns
Vessels involved	2.33 ± 8.1	1.97 ± 0.68	2.64 ± 0.48	< 0.0001
LMT	35	14 (12.6%)	21 (30%)	0.006
Urgency	28	11 (10%)	17 (24.2%)	0.012
IABP	25	11	14	ns
Concomitant malignancy	20	15	5	ns

*: Patients receiving 1 or 2 grafts, **: Patients receiving 3 or more grafts
OMI: old myocardial infarction, AMI: acute myocardial infarction, PCI: percutaneous coronary intervention, CABG: coronary artery bypass grafting, LVEF: left ventricular ejection fraction, LMT: left main trunk lesion, IABP: intraaortic balloon pumping

for OPCAB.

Patient characteristics are shown in **Table 1**: Acute myocardial infarction was a complication in 23 patients. Thirty-five patients had a critical left main trunk lesion (LMT). One hundred and fifty-three patients underwent elective surgery, whereas 28 patients with acute coronary syndrome underwent an emergent or urgent operation. Twenty patients had a concomitant malignant neoplastic disorder. Our current trend in the OPCAB practice has been to revascularize as many coronary arteries as possible. To clarify the feasibility of multiple OPCAB, the 181 patients were divided into 2 groups: Group I (N=111): patients receiving 1 or 2 grafts; and Group II (70): patients receiving 3 or more grafts.

Operative technique

Anesthesia was induced with midazoram 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. Diltiazem, nicolandil and isosorbide dinitrate were administered throughout the operation. Anticoagulation was achieved with heparin at 200 U/kg after all grafts were harvested for coronary revascularization. Transesophageal echocardiography was used for additional monitoring in all cases. Perfusionist standby was available for all patients. Blood pressure was optimized carefully during the procedure with the selective use of vasoconstrictors. Intra-aortic balloon pump (IABP) was applied, if necessary, for patients with a critical LMT lesion of more than 90%.

The MIDCAB was performed through a small 4th intercostal left anterior thoracotomy incision with the patient in the anterolateral decubitus position with a 20～30 degree tilt. The LITA was harvested directly with a retractor system (Thora-LIFT, United States Surgical Co., USA), which created a wider visual tunnel for exposure of the LITA along its entire length. The techniques of local coronary stabilization and anastomosis were the same as in patients with sternotomy, as mentioned below.

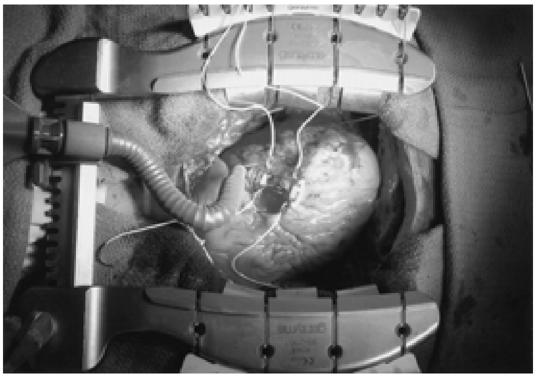

Fig. 1 A local coronary stabilizer. Two silicon elastic tapes were passed underneath the coronary artery to control bleeding and obtain local stabilization.

Sternotomy was employed in all patients who required revascularization of 2 or more coronary vessels. In addition to left-sided deep pericardial retraction sutures and table rotation, we placed a right vertical pericardiotomy on the right-sided diaphragmatic surface 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 with a mechanical stabilizer (Immobilizer$_{TM}$, Genzyme Corp. Cambridge, MA, U.S.A.) (**Fig. 1**). 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 11.0 J (SPSS Inc, Chicago, IL). Comparisons between the two groups were performed using unpaired Student's t test. The chi square test using the exact test was used for comparison of categorical data. All p values were two-tailed, and a p value of less than 0.05 was considered significant.

Results

Two patients, in whom OPCAB was attempted were converted to on-pump CABG intraoperatively, one due to hemodynamic instability and the other because of unsuitable coronary anatomy. The operative results are shown in **Table 2**. In 76 Group I patients and all Group II patients, the operation was performed through a median sternotomy. For the remaining Group I patients, the operation was performed through a left thoracotomy in 27, a subxiphoid approach in 6 and a combined one in 2 patients.

Death occurred in 3 patients with acute coronary syndrome who had to undergo an urgent operation. Two of them (Group I patients) died of pre-existing respiratory failure. The other patient, who had recovered from cardiogenic shock due to left main trunk occlusion, died of multiple organ failure despite successful revascularization.

Cerebral infarction occurred in 2 patients on the 3rd and 5th postoperative day. Three patients suffered from respiratory failure resulting in the death of 2 of them. A sudden occurrence of ventricular arrhythmias necessitating cardiopulmonary resuscitation appeared in one patient during her stay in the ICU. Perioperative myocardial infarction, which was diagnosed by the elevation of serum CPK-MB over 100 units/dl and the appearance of q wave in the ECG, occurred in 3 patients in Group I and one in Group II. Thirty-five patients received 2 to 6 units of transfusion. One hundred and fifty-six patients were extubated within 6 hours after operation in the ICU.

Table 2 Operative variables in each group

	Group I (n = 111)	Group II (n = 70)	p value
approach			
sternotomy	76	70	
left thoracotomy	27		
subxiphoid	6		
combined	2		
Grafted vessele	1.51 ± 0.50	3.44 ± 0.65	< 0.0001
Operative time (min.)	163.9 ± 53.9	209.5 ± 40.8	< 0.0001
Grafts:			
LITA	89 (80.2%)	69 (98.6%)	< 0.0001
RITA	31 (27.9%)	55 (78.6%)	< 0.001
GEA	14	9	ns
RA	17 (15.3%)	42 (60%)	< 0.0001
SVG	17	17	ns
Composite graft	33 (30%)	62 (88.6%)	< 0.001
Concomitant surgery	13	3	ns
IABP	7 (6.3%)	16 (22.9%)	p = 0.001
transfusion			
yes	24	11	ns
no	87	59	
Respiratory support			
> 6 hours	18	7	ns
≦ 6 hours	93	63	
Complications	6 *	3 **	ns
PMI	3	1	ns
Death	2	1	ns

LITA: left internal thoracic artery, RITA: right internal thoracic artery, GEA: right gastroepiploic artery, RA: radial artery, SVG: saphenous vein graft, PMI: perioperative myocardial infarction
*: respiratory failure 2, cerebral infarction 1, sternal dehiscence 1, ventricular arrhythmia 1
**: respiratory failure 1, cerebral infarction 1, multiple organ failure 1

The number of grafted vessels in Group II was 3 to 5 with a mean of 3.44. The mean operative time was 163 minutes in Group I and 209.5 minutes in Group II. The percentage of the use of arterial grafts such as LITA, RITA and RA, was significantly higher in Group II than in Group I. The frequency of the use of the composite graft was also significantly higher in Group II than in Group I. Details of the grafts used in Group II are shown in **Tables 3 and 4**. In most instances, a free graft (free right ITA, RA and SVG) was attached to the side of the in-situ graft to make a Y-shape composite graft (**Fig. 2**), or was anastomosed to the graft in an end-to-end fashion to make an I-shaped composite graft (**Fig. 3**). Only 5 SVGs were attached to the ascending aorta. The sequential grafting technique was used to revascularize 2 or more coronary territories with a single graft in patients with multi-vessel disease.

Angiographic examination was performed within 3 months postoperatively in 63 Group I patients and in 35 Group II patients (**Table 5**). The patency rate of the LITA, RITA, GEA, RA and SVG in Group I was 49/50, 8/8, 9/10, 4/4 and 7/8, respectively. The patency rate of these grafts in Group II was: LITA, 33/33; RITA, 25/25; GEA, 6/6; RA, 16/16 and SVG 8/8.

Discussion

The availability of cardiopulmonary bypass expanded surgical revascularization for ischemic heart disease. Results in larger series reported

Table 3 Details of the grafts in Group II

	LITA	RITA	GEA	RA	SVG
In situ graft	69	35	8	/	/
Free graft	0	21	1	42	17
Inflow source					
LITA	/	21	0	24	1
RITA	0	/	1	21	11
GEA	0	0	/	1	0
Aorta	0	0	0	0	5
Sequential graft	8	12	1	24	4

Table 4 Types of composite grafts in Group II patients

Composite graft	Y-shaped	I-shaped
LITA-RITA	20	1
LITA-RA	21	3
LITA-SVG	2	0
RITA-RA	1	20
RITA-SVG	3	8
GEA-RA	1	0

Y- or I- : Explained in the text.

Table 5 Graft patency in each group

	Group I	Group II
LITA	49/59 (98%)	33/33 (100%)
RITA	8/8 (100%)	25/25 (100%)
GEA	9/10 (100%)	6/6 (100%)
RA	4/4 (100%)	16/16 (100%)
SVG	7/8 (87.5%)	8/8 (100%)

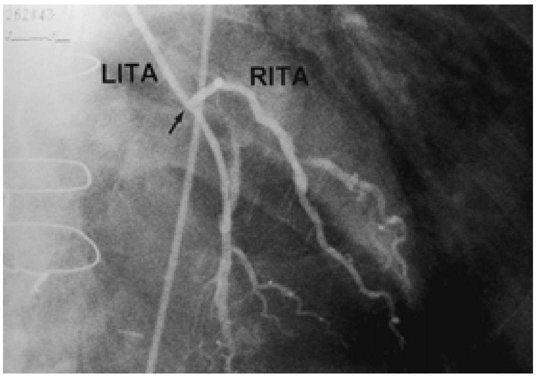

Fig. 2 A Y-shaped composite graft. In this case, a free RITA that was attached to the side of the in situ LITA (arrow) was anastomosed to the ramus intermedius branch. The LITA was anastomosed to the LAD.

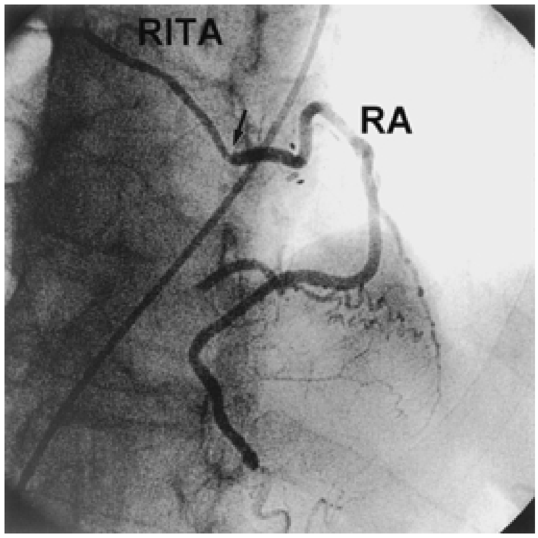

Fig. 3 An I-shaped composite graft. In this case, a radial artery (RA) that was anastomosed to the in situ RITA in an end-to-end fashion (arrow) revascularized 3 coronary arteries.

overall mortalities between 2～4% in CABG[6,7]. Morbidity has remained significant, however, and may have increased as older patients with multiple organ dysfunctions have been accepted for CABG.

CPB itself and manipulations necessary for the performance of CPB play a major role in potential postoperative complications. Interaction between blood and a foreign artificial surface activates complement and neutrophils to produce a whole-body inflammatory reaction[8]. Intrapulmonary sequestration of white blood cells with generation of oxygen free radicals and protease enzymes causes interstitial edema resulting in the need for postoperative ventilation. These mechanisms, together with cerebral microembolism, also

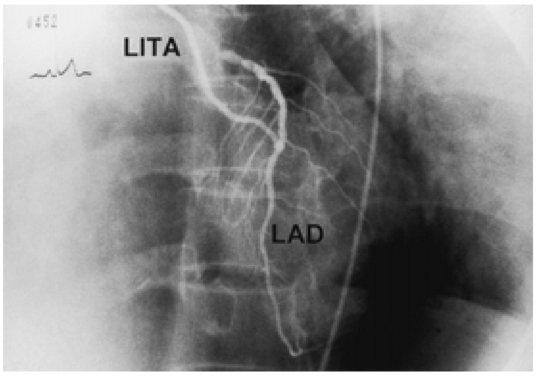

Fig. 4 LITA-LAD anastomosis through a left anterior small thoracotomy.

contribute to the deleterious effects of CPB on cerebral neuropsychological function. Thus, elimination of CPB has been shown to reduce mortality and complications in some series, especially for those who are at risk of morbidity from CPB[9].

In the early period of this technique, to simply perform a LITA-left anterior descending artery (LAD) anastomosis, minimally invasive direct coronary artery bypass grafting (MIDCAB) through a small anterior thoracotomy attracted the interest of surgeons, as they could avoid sternotomy[10]. However, the procedure was limited mainly to patients with single-vessel disease. The surgeons' focus has now shifted towards the avoidance of the influence of CPB, rather than the sternotomy itself, when managing patients with multi-vessel disease. The recent advancement in the technology of local coronary stabilizers has improved the outcome and widened the indication of the procedure.

In our current series, the first case with an LITA-LAD anastomosis was performed through a median sternotomy, followed by a series of MIDCAB through a small anterior thoracotomy to construct a single LITA-LAD anastomosis (**Fig. 4**). Thereafter, we began multiple graftings for multi-vessel disease patients. Despite its technically demanding characteristics, the recent advancement in technology and accumulation of experience have paved the way for a more complex coronary revascularization with OPCAB. Complete revascularization can now be achieved with this technique even in patients with multi-vessel coronary disease[11-13].

It is of note that the avoidance of blood transfusion was achieved equally in both groups (78.4% and 84.3%, respectively) and more than 80% of the patients were extubated within 6 hours of operation in both groups (83.8% and 90%, respectively) (**Table 2**). Although no comparison between the OPCAB patients and on-pump patients is available, the results of this series are comparable to those of other reports[11-13].

Avoiding mechanical manipulation of the diseased aorta is crucial in the OPCAB for the prevention of intraoperative complications, such as cerebrovascular atheromatous emboli or acute aortic dissection[14,15]. The principle of "aortic no touch" necessarily means the avoidance of placing a clamp on the aorta. Therefore, the in situ (pedicled) arterial grafts should be selected as grafts for the coronary arteries as well as providing an inflow source for the free grafts. Consequently, we used as many in-situ arterial grafts as possible in this series such as the ITAs and GEA. A free graft was attached to the side of the in-situ arterial graft to make a Y-shaped composite graft, or was anastomosed to the graft in an end-to-end fashion to make an I-shaped composite graft. Only 5 SVGs were attached to the ascending aorta. The sequential grafting technique was used aggressively to revascularize 2 or more coronary territories with a single graft in patients with multi-vessel disease.

In February 1999, we first applied the OPCAB procedure for a patient with unstable angina who required an emergency operation. Since then, we have performed OPCAB in 28 patients with acute coronary syndrome. In the initial period of this small series, only 1 or 2 vessels were grafted. More recently, however, complete revascularization has been our goal for these patients and the number of grafted vessels has increased up to 5. Even a multi-vessel patient with a critical LMT lesion could be revascularized safely under an IABP support with OPCAB.

The evolution of OPCAB has widened the possibilities for surgical treatment of coronary artery disease in patients with various comorbidities for which CPB is contraindicated. We have experienced

20 patients with malignant neoplastic disorders who underwent OPCAB. All these patients underwent surgery successfully for a malignancy simultaneous to or secondary to the OPCAB.

It is generally believed that CPB enhances the systemic inflammatory response while attenuating the immune response of the body. At the present time, there is no definite data on how, and to what extent, CPB influences the outcome of patients with a malignant neoplasm who undergo open heart surgery. The CPB, however, does require prolonged postoperative care of the patient, so if the patient has to undergo further surgery for a malignancy or other comorbid state, delaying that surgery can influence its postoperative outcome. Since myocardial revascularization is not the final goal of treatment for these patients, OPCAB can yield a better outcome with a shorter recovery time without the adverse effects of the CPB than can the on-pump CABG[16,17].

In conclusion, in light of our 5-year experience, OPCAB can be performed safely and efficiently even in patients with multi-vessel coronary disease requiring multiple myocardial revascularization. The OPCAB technique has certainly widened the indication of surgical coronary revascularization for older and riskier patients.

To prove the efficacy and superiority of the OPCAB procedure over on-pump CABG, prospective randomized studies will be needed.

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