

## AORTIC ARCH REPAIR WITH CORONARY ARTERY REVASCULARIZATION

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**Abstract:** Objective: Simultaneous aortic arch repair and coronary artery bypass are associated with considerable morbidity and mortality. We retrospectively analyzed our experience with on- and off-pump coronary artery bypass (CAB) combined with aortic arch repair.

Methods: Before aortic arch repair, distal coronary artery anastomosis was constructed on the arrested heart under CAB (ONCAB:  $n=14$ ), or on the beating heart before CAB (OPCAB:  $n=18$ ). We also analyzed data from patients after isolated total arch replacement (TAR:  $n=20$ ).

Results: Compared with ONCAB, OPCAB was associated with shorter periods of myocardial ischemia ( $133\pm24$  vs.  $180\pm48$  min,  $P=0.017$ ) and cardiopulmonary bypass ( $239\pm35$  vs.  $306\pm61$  min,  $P=0.002$ ), less prolonged postoperative ventilation (33% vs. 79%,  $P=0.027$ ) and lower postoperative peak CK-MB levels ( $35\pm19$  vs.  $99\pm124$  U/L,  $P=0.012$ ). One (6%) patient after OPCAB and 3 (21%) after ONCAB ( $P=0.210$ ) died in hospital. Compared with the TAR group, the myocardial ischemic periods after OPCAB ( $125\pm30$  vs.  $133\pm24$  min,  $P=0.401$ ) and postoperative outcomes were similar.

Conclusions: Aortic arch repair with OPCAB offers an option for treating aortic arch aneurysm accompanied by atherosclerotic coronary artery disease.

**Key words:** thoracic aortic aneurysm, heart disease, off-pump coronary artery bypass, cardiopulmonary bypass, operative surgical procedures

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## INTRODUCTION

Surgically treating aortic arch aneurysm and atherosclerotic coronary artery disease is very challenging. Simultaneous aortic arch repair (AAR) and coronary artery bypass grafting (CABG) are associated with considerable operative morbidity and mortality<sup>1,2)</sup>. This combined procedure is inevitable with prolonged periods of cardiac arrest with myocardial ischemia and cardiopulmonary bypass (CPB), which are both significant risk factors for adverse outcomes in aortic arch surgery<sup>2-6)</sup>. Furthermore, appropriate intraoperative myocardial protection is mandatory for the hypertrophied heart<sup>7)</sup> with persistent hypertension to avoid perioperative cardiac dysfunction, which is closely associated with early operative mortality<sup>3)</sup>.

Recent technical improvements in off-pump coronary artery bypass (OPCAB)<sup>8,9)</sup> have allowed us to introduce OPCAB into this simultaneous operation<sup>10)</sup> in an effort to improve the surgical outcomes of patients undergoing AAR with coronary artery revascularization. Here, we retrospectively compare our preliminary experiences with on-and off-pump coronary artery bypass surgery combined with total arch replacement (TAR) to determine the feasibility of OPCAB in the treatment of such patients complicated with multi-organ arteriosclerosis.

## MATERIALS AND METHODS

*1. Patients*

Between November 2000 and August 2006, 32 patients with atherosclerotic degenerative aortic arch aneurysm underwent total arch replacement (TAR) using antegrade selective cerebral perfusion (ASCP) and additional coronary artery revascularization. Patients with significant angiographic stenosis (>75%) in the major coronary arteries underwent simultaneous coronary revascularization.

ONCAB group ( $n=14$ ): All coronary artery bypass anastomoses in this group were conventionally constructed under CPB.

OPCAB group ( $n=18$ ): Distal coronary artery anastomoses were constructed on the beating heart before CPB.

TAR group ( $n=20$ ): Patients who underwent TAR without CABG between 2001 and 2005 served as the control group.

Table 1 shows the demographic data of the patients, most of whom had a long history of hypertension. Left ventricular hypertrophy was identified by echocardiography and/or electrocardiography. Old cerebral infarction, revealed by computed tomography (CT) or by nuclear magnetic resonance imaging, was also a frequent comorbidity among these patients. Renal dysfunction is dialysis-dependent renal failure. All the demographic data were similar, except patients in TAR group frequently had old cerebral infarction detected by CT.

Table 1. Demographic data of the patients

	TAR ( <i>n</i> =20)	OPCAB ( <i>n</i> =18)	ONCAB ( <i>n</i> =14)	<i>P</i> value	
				TAR : OPCAB	OPCAB : ONCAB
Age	70±7	70±7	71±5	0.681	0.689
Range	49-79	62-80	64-79		
Gender (M/F)	17/3	17/1	11/3	0.678	0.420
Diseased coronary artery	0	1.5±0.8	1.5±0.8	<0.001*	0.964
Range		1-3	1-3		
Hypertension	19 (95%)	18 (100%)	13 (93%)	1.052	0.875
Left ventricular hypertrophy	8 (40%)	11 (62%)	10 (71%)	0.329	0.819
LV ejection fraction <0.40	0	1 (6%)	0	0.94	1.125
Previous PCI	0	2 (12%)	0	0.435	0.617
Old cerebral infarction	13 (65%)	5 (28%)	3 (21%)	0.047*	1.007
Diseased cerebral artery	0	3 (17%)	0	0.193	0.329
COPD	1 (5%)	1 (6%)	0	1.459	1.125
Renal dysfunction	0	1 (6%)	2 (14%)	0.947	0.807

TAR: Patients underwent total arch replacement without coronary revascularization. OPCAB: distal coronary artery anastomosis constructed on beating heart before cardiopulmonary bypass period. ONCAB: distal coronary artery anastomosis constructed under cardiopulmonary bypass. LV: left ventricle. PCI: percutaneous coronary intervention. COPD: chronic obstructive pulmonary disease. Data are expressed as means±SD (range), unless otherwise stated. \*Statistically significant.

## 2. Surgical techniques

### 2-1. OPCAB

Off-pump Coronary Artery Bypass: The technical details of off pump coronary artery anastomosis have been described<sup>9)</sup>. Briefly, a median sternotomy was performed and then the coronary arteries were exposed using a deep pericardial suture and a heart retractor (Starfish®, Medtronic Inc., Minneapolis, MN, USA). Coronary artery anastomoses were constructed using a running 7-0 monofilament suture, an Octopus stabilizer (Medtronic Inc.), a CO<sub>2</sub> blower and an intraluminal shunt.

Aortic arch repair after OPCAB: Technical details of AAR using ASCP have been described<sup>11)</sup>. Briefly, The CPB was established with right atrium drainage and artery perfusion through the bilateral axillary and femoral arteries. During core cooling and aortic cross clamping, antegrade cold blood cardioplegia was delivered through the aortic root as well as pre-attached coronary artery bypass conduits. The proximal end of the coronary artery graft was attached to the ascending aorta, followed by intermittent antegrade and retrograde cardioplegia delivery. Open distal anastomosis using a branched Dacron graft proceeded under antegrade cerebral perfusion through the left carotid and bilateral axillary arteries at a body temperature of 25°C. Distal body perfusion was restarted through the branched graft. After proximal graft-ascending aorta anastomosis, the arch graft was de-

clamped to start perfusing the myocardium. The left subclavial, left common carotid and brachiocephalic arteries were reattached to the branched graft, then the patient was weaned off CPB.

## 2-2. ONCAB

Distal coronary artery bypass anastomoses were constructed on the arrested or fibrillating heart under CPB while cooling before AAR. Proximal coronary bypass anastomoses were constructed on the ascending aorta if appropriate, while cooling with aortic cross-clamping or while re-warming with aortic lateral-clamping. Proximal coronary artery anastomosis was constructed on the arch graft when the ascending aorta was not suitable.

We evaluated intra-operative data and early outcomes, CPB time, myocardial ischemia, early graft patency, neurological dysfunction, renal dysfunction and operative death.

## 2-3. Statistical analysis

Data are expressed as means $\pm$ standard deviation unless otherwise stated. Differences between the two groups were analyzed using the Mann-Whitney U test,

Table 2. Coronary artery bypass grafting

	OPCAB (n=18)	ONCAB (n=14)	P value
Distal anastomosis			
Average number (range)	1.5 $\pm$ 0.8 (1~3)	1.5 $\pm$ 0.8 (1~3)	0.964
$\geq 2$	6 (33%)	5 (36%)	1.395
Grafted coronary artery			0.049*
LAD, Dx	12 (44%)	5 (24%)	
LCX	5 (19%)	9 (43%)	
RCA	10 (37%)	7 (33%)	
Proximal anastomosis			
Average number (range)	1.3 $\pm$ 0.7 (0~3)	1.3 $\pm$ 0.5 (1~2)	0.600
Inflow site			0.727
Ascending aorta	22 (88%)	16 (80%)	
Arch graft	1 (4%)	2 (10%)	
In-site	2 (8%)	2 (10%)	
Type of graft conduit		.016*	
ITA		2 (8%)	2 (10%)
RA		10 (42%)	1 (5%)
SVG		12 (50%)	17 (85%)

OPCAB: distal coronary artery anastomosis constructed on beating heart before cardiopulmonary bypass period. ONCAB: distal coronary artery anastomosis constructed under cardiopulmonary bypass. LAD: left anterior descending artery. Dx: diagonal artery. LCX: left circumflex artery. RCA: right coronary artery. ITA: internal thoracic artery. RA: radial artery. SVG: saphenous vein graft. Data are expressed as means $\pm$ SD, unless otherwise stated. \*Statistically significant.

$\chi^2$  or Fisher's exact test when appropriate.

## RESULTS

All patients underwent TAR with a branched graft. Table 2 shows the results of coronary revascularization. The average numbers of distal and proximal coronary bypass graft anastomoses per patient were similar between the OPCAB and ONCAB groups. Five (36%) and 6 (33%) of the patients in the OPCAB and ONCAB groups, respectively, had multi-vessel coronary artery disease. The main area of revascularized coronary artery was the anterior (44%) and lateral (43%) walls in the OPCAB and ONCAB groups. A free graft conduit was preferred for both groups (92% and 90% in OPCAB and ONCAB, respectively), while the radial artery was more frequently used in the OPCAB group.

Table 3 shows the intra-operative data and early postoperative outcomes. The period of CPB was significantly shorter after OPCAB than ONCAB. The longest

Table 3. Intra-operative data and early outcomes

	TAR ( <i>n</i> =20)	OPCAB ( <i>n</i> =18)	ONCAB ( <i>n</i> =14)	<i>P</i> value	
				TAR : OPCAB	OPCAB : ONCAB
Intra-operative data					
Cardiopulmonary bypass (min)	207±38	239±35	306±61	0.021*	0.002*
Range (min)	142~281	187~303	201~417		
>300 min	0	1 (6%)	7 (50%)	0.947	0.012*
Myocardial ischemia (min)	125±30	133±24	180±48	0.401	0.017*
Range (min)	90~192	99~178		97~234	
>180 min	1 (6%)	0	5 (36%)	1.053	0.020*
Early outcome					
Early (2~3 wk) graft patency	N.A.	18/19 (95%)	15/15 (100%)		1.117
New myocardial infarction	1 (5%)	0	2 (14%)	1.053	0.183
Peak CK-MB (U/L)	43±39	35±19	99±124	0.885	0.012*
Neurological dysfunction	2 (10%)	3 (17%)	4 (28%)	0.896	0.183
Transient	1 (5%)	3 (17%)	2 (14%)	0.525	1.248
Permanent	1 (5%)	0	2 (14%)	1.053	0.183
Prolonged (>48 h) ventilation	6 (30%)	6 (33%)	11 (79%)	0.550	0.027*
Dialysis	0	1 (6%)	3 (21%)	0.947	0.210
Early (<30 d) mortality	1 (5%)	0	2 (14%)	1.053	0.183
In-hospital mortality	1 (5%)	1 (6%)	3 (21%)	0.730	0.210

TAR: Patients underwent total arch replacement without coronary revascularization. OPCAB: distal coronary artery anastomosis constructed on beating heart before cardiopulmonary bypass period. ONCAB: distal coronary artery anastomosis constructed under cardiopulmonary bypass. CK-MB: creatinine kinase myocardial band. In-hospital mortality includes early mortality. Data are expressed as means±SD, unless otherwise stated. \*Statistically significant.

CPB time was 303 minutes in one patient in the OPCAB group who had triple-vessel disease. The period of CPB in 17 of 18 (94%) patients was <300 minutes. The period of myocardial ischemia (cardiac arrest) was not any shorter in the OPCAB, than in the TAR group, but it was significantly shorter than that in the ONCAB group. The myocardial ischemic duration for all of the patients in the OPCAB group was <180 minutes.

No postoperative myocardial failure, perioperative new Q-wave myocardial infarction, permanent neurological dysfunction or early (<30 days) operative mortality occurred after OPCAB. The postoperative peak value of the serum creatine-kinase myocardial band (CK-MB) and the incidence of prolonged ventilation were lower in the OPCAB, than in the ONCAB group. Three hospital deaths (21%) occurred due to myocardial dysfunction in 2 patients and severe neurological dysfunction in 1 patient in the ONCAB group. A 74 year-old woman with chronic renal failure died of massive gastrointestinal bleeding during hemodialysis on the 50<sup>th</sup> postoperative day in the OPCAB group, resulting in an in-hospital mortality rate of 6%. Postoperative outcomes were similar between the TAR and OPCAB groups (Table 3).

#### DISCUSSION

Patients with multi-organ arteriosclerosis frequently have atherosclerotic aortic arch aneurysms complicated with coronary artery disease<sup>1,2)</sup>. The reported hospital mortality rates after simultaneous AAR and coronary revascularization are between 14% and 21% even at large-volume centers. On the other hand, the reported mortality rates after AAR without CABG are between 7% and 9%<sup>1,2)</sup>. Several multivariate analyses have demonstrated that additional CABG with AAR is a significant risk factor for increased postoperative adverse effects such as transient neurological dysfunction<sup>2,6,12)</sup>, prolonged ventilation<sup>2)</sup> and hospital mortality<sup>12,13)</sup>. Di Bartolomeo and colleagues recently used stepwise logistic regression analysis to analyze the outcomes of 96 patients after ascending aorta/arch replacement using moderate hypothermic circulatory arrest and ASCP. They concluded that concomitant CABG is an independent predictor of neurological dysfunction and hospital mortality<sup>12)</sup>. Fleck and colleagues reported that concomitant CABG is an independent risk factor for mortality according to their findings of multivariate logistic analyses of 165 consecutive patients who underwent ascending aortic repair using ASCP<sup>13)</sup>. Most recently, Khalady and associates analyzed consecutive 501 patients who underwent aortic arch surgery with hypothermic arrest with ASCP, showing that CPB duration is a risk factor for mortality, and that coronary artery disease is a risk factor for temporary neurological dysfunction<sup>14)</sup>.

Several clinical studies have demonstrated that myocardial ischemic time<sup>2)</sup> and CPB time<sup>3-6)</sup> in AAR are significant risk factors for operative mortality. Ehlich and associates analyzed data from 443 patients who underwent AAR using deep hypoth-

emia and circulatory arrest (HCA) with/without retrograde cerebral perfusion, and concluded that both concomitant CABG and elongated myocardial ischemia time are statistically associated with operative morbidity such as transient or permanent neurological dysfunction and prolonged ventilation<sup>2)</sup>. Di Eusanio and colleagues studied 588 patients who underwent AAR using ASCP by logistic regression analysis, and demonstrated that CPB time is the sole independent predictor of hospital mortality and that additional CABG predicts transient neurological dysfunction<sup>6)</sup>. Other recent multivariate analyses of patients after AAR using HCA have also shown that prolonged CPB time predicts hospital mortality<sup>3,5)</sup>.

Kazui and colleges recently found in a multivariate analysis of 220 patients who underwent TAR with ASCP, that CPB time of >300 minutes is an independent determinant of permanent neurological dysfunction and in-hospital mortality<sup>4)</sup>. The longest CPB time was 303 minutes for a patient with triple-vessel disease in the OPCAB group, whereas it was <300 minutes in all of the other patients (94%), in whom the risk of adverse postoperative effects such as those associated with prolonged (>48 h) ventilation were reduced. These results indicated that adding OPCAB to the combined operation would be more beneficial for patients with multiple coronary artery anastomoses that require prolonged cardiopulmonary time when undergoing on-pump coronary artery bypass. Despite recent improvements in aortic surgical techniques, prolonged CPB time should be anticipated during distal anastomosis on a fragile or calcified descending aorta or during lengthy suture-site hemostasis deep in the left thorax. The ability to avoid unnecessary CPB time before AAR by introducing OPCAB allows surgeons to reserve extra time to manage such challenging situations under CPB.

Left ventricular hypertrophy associated with hypertension has been identified as an important risk factor for cardiovascular morbidity and mortality<sup>15)</sup>. Several morphological, metabolic and physiological adaptive changes in the hypertrophied myocardium result in increased susceptibility to ischemic injury<sup>7,16)</sup>. Consequently, left ventricular hypertrophy is considered to predict morbidity<sup>17)</sup> and mortality<sup>18)</sup> after coronary artery bypass surgery. Thus, better myocardial protection is mandatory for the hypertrophied heart<sup>7)</sup> as we frequently observed in this series of patients. A recent multicenter prospective randomized trial that included 800 patients with CABG discovered that increased postoperative peak CK-MB is a powerful predictor of severe postoperative left ventricular dysfunction and mortality associated with CABG<sup>19)</sup>.

Several recent comparisons of myocardial protection between on- and off-pump coronary artery bypass surgeries have demonstrated that OPCAB is associated with better myocardial protection<sup>20)</sup>. The introduction of OPCAB into AAR with CABG has several theoretical advantages. First, the introduction of OPCAB can minimize myocardial ischemic time, which decreases the risk of postoperative cardiac failure<sup>2,3)</sup>, in contrast to the conventional procedure in which distal coronary anastomoses are produced on the arrested heart during myocardial ischemia. None of

our patients in the OPCAB group, even with triple-vessel coronary disease, experienced over 180 min of myocardial ischemia, or developed new perioperative Q-wave myocardial infarction. Secondly, the cardioplegia solution can be delivered through pre-attached coronary artery bypass grafts into the myocardium from the start of aortic cross clamping. From this viewpoint, we prefer free bypass graft conduits such as the radial artery and saphenous vein rather than in-situ arterial grafts. The postoperative peak CK-MB was significantly lower in the OPCAB, than in the ONCAB group, suggesting more effective myocardial protection using OPCAB in this combined operation.

The main limitation of this study is its retrospective, non-randomized nature, combined with a small patient cohort. The effects on neurological dysfunction and hospital mortality in AAR remain to be elucidated.

#### CONCLUSION

Our preliminary experience suggests that introducing OPCAB into TAR combined with coronary revascularization is feasible and improves surgical outcomes in elderly patients with aortic arch aneurysms and coronary artery disease.

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