

Aortic Arch Aneurysm Complicated with Coronary Artery Disease: Still a Surgical Challenge?

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Recent surgical strategies and outcomes for the simultaneous operation of aortic arch repair (AAR) and coronary artery bypass grafting (CABG) were reviewed. The surgical treatment of aortic arch aneurysm complicated with coronary artery arteriosclerosis has been a challenge. In spite of recent improvements in cerebral protection during AAR such as deep hypothermia and circulatory arrest with/without retrograde cerebral perfusion, or antegrade selective cerebral perfusion (SCP), additional CABG poses a considerable surgical risk resulting in extremely higher mortality rates when compared with solo AAR. To minimize the cardiac ischemic time, several techniques such as distal coronary artery anastomosis on the perfused fibrillating heart, and coronary artery perfusion through a cardioplegic line during AAR have been employed. Recently, open stent grafting instead of aortic distal anastomosis has been attempted to minimize the cardiopulmonary time and operative complexity. Our recent experience suggested off-pump coronary artery bypass and AAR with the aid of SCP decreased cardiac ischemic time and cardiopulmonary time followed by improved operative morbidity and mortality. Further less-invasive surgical modalities that enhance the adequate myocardial protection and minimize the adverse effect of cardiopulmonary bypass can improve the outcome of this demanding operation for these elderly patients with aortic arch aneurysm and coronary artery occlusive disease. (Ann Thorac Cardiovasc Surg 2002; 8: 62–8)

Key words: aortic arch aneurysm, coronary artery atherosclerosis, aortic arch repair, coronary artery bypass grafting, selective cerebral perfusion

Introduction

The surgical treatment for thoracic aneurysm has been a challenge especially in the group of high-risk, elderly patients. The number of operations for thoracic aneurysms has been increasing year by year this decade. According to the annual report by the Japanese Association for Thoracic Surgery,¹⁾ there has been a steady 10% increase per year in thoracic aneurysm operation. However, the operative mortality rate in thoracic aneurysm surgery especially for the aortic arch was not satisfac-

tory, which was reported as 12.2% by the Japanese Association for Thoracic Surgery Database in 1999. In most cases, the leading causes of early postoperative death in aortic arch surgery were permanent cerebral dysfunction, myocardial failure and bleeding.

Arteriosclerosis is a disorder involving the aorta as well as the arteries in multi-organs such as the brain, heart and kidney. The patients with degenerative aortic arch aneurysms often have coronary artery atherosclerotic disease as one of the multi-organ atherosclerosis. The simultaneous operation of aortic arch repair (AAR) and coronary revascularization has been carried out in about 15% to 30% of all aortic arch surgery.^{2,3)} The operation for elderly patients with concomitant atherosclerotic lesions in the aortic arch and coronary artery has been a surgical challenge with a high incidence of operative mortality. Herein, this paper reviews the current strate-

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Table 1. Reported surgical outcome in the aortic arch replacement with/without coronary artery bypass

Author	Year	Site	Method	Mortality (number of cases)		Reference
				CABG (+)	CABG (-)	
Crawford	1989	Ascending/arch	HCA	16% (121)	7% (596)	[2]
Hayashi	1997	Arch	SCP	50% (6)	24% (137)	[9]
Sadahiro	1997	Ascending/arch	SCP	55% (11)	10% (91)	[12]
Ohkita	1998	Arch	HCA+RCP	21% (19)	9% (129)	[6]
Ehrlich	2000	Ascending/arch	HCA	14% (80)	9% (311)	[3]
Yamashiro	2001	Arch	SCP	27% (15)	20% (25)	[11]

HCA: hypothermic circulatory arrest, SCP: selective cerebral perfusion, RCP: retrograde cerebral perfusion

gies and surgical results for the treatment of concomitant aortic arch aneurysm and coronary atherosclerotic lesions.

A Surgical Challenge?: Review of Reported Mortality

AAR necessitating cerebral protection is an evolving surgical procedure in this decade. Improved surgical outcome, decreased morbidity and mortality has been reported recently using hypothermic circulatory arrest (HCA),²⁻⁵ HCA added with retrograde cerebral perfusion (RCP),^{6,7} and selective cerebral perfusion (SCP).⁸⁻¹² Ehrlich and colleagues reported 9% mortality by analyzing 443 patients who underwent ascending/hemiarch replacement with HCA from 1986 through 1998.³ Ueda et al. reported 10% mortality out of 249 patients for aortic arch surgery with HCA and RCP from 1994 through 1996.⁷ Kazui and colleagues reported 13% mortality in 220 patients for total arch replacement with SCP during 1990 and 1999.¹⁰

Concern about the simultaneous operation of AAR and coronary artery bypass grafting (CABG) has been focused on in detail by reports from several Japanese institutes,⁶⁻¹² however, they include a relatively small number of patients. A large number of patients with this concomitant operation have been reported by a few institutes in the United States,^{2,3} however, without any details such as number of diseased coronary arteries, method of myocardial protection and incidence of perioperative myocardial infarction. According to these reported surgical outcomes, the simultaneous operation of AAR and coronary revascularization has been associated with a significantly higher mortality rate than solo AAR (Table 1). This simultaneous operation roughly doubled the mortality rate in AAR between 14% and 55% regardless of the method of cerebral protection. The most frequent

adverse effects were perioperative myocardial failure, permanent cerebral dysfunction and massive intraoperative hemorrhage followed by multi-organ failure.

Why does Concomitant CABG Increase the Morbidity and Mortality?

The concomitant CABG in the AAR has been recognized as a significant risk factor for increased operative morbidity³ and mortality.^{3,12} Ehrlich et al. analyzed 271 elective cases of AAR with HCA to determine the variables associated with the adverse outcome.³ Univariate assessment revealed that a history of coronary artery disease, need for concomitant procedure, coronary artery bypass surgery, cerebral ischemic time, duration of cardiopulmonary time, myocardial ischemic time, etiology of the aneurysm and presence of any complications were significantly associated with an adverse outcome. Multivariate analysis showed three risk factors for an adverse outcome: performance of concomitant procedure, duration of cerebral ischemia, and occurrence of any postoperative complication. In their series, CABG consisted of 65% of the concomitant procedure. Several recent reports also described CABG as a significant risk factor for operative morbidity and mortality in the patients who underwent AAR using SCP.^{11,12} Ehrlich and associates also demonstrated that concomitant CABG and elongated cardiopulmonary bypass time are associated with operative morbidity such as transient or permanent neurologic dysfunction and prolonged intubation.³ They suggested that the presence of coronary artery disease may be an indication of cerebrovascular atherosclerosis in these patients, which puts them at higher risk of cerebral dysfunction postoperatively.

Several factors should be considered in this simultaneous operation for surgical success; coronary artery revascularization, myocardial protection and prolonged

myocardial ischemic time during AAR and prolonged cardiopulmonary bypass time associated with coronary revascularization.

Adequate coronary revascularization is mandatory to prevent perioperative myocardial infarction that is followed by acute cardiac failure. Regardless of the presence of a patient's symptoms, the diseased major coronary artery should be revascularized to avoid catastrophic heart failure. Recently, Ueda and associates reported that incomplete revascularization of the major coronary arteries with significant stenosis is a significant risk factor for perioperative cardiac events in the patients with thoracic aortic aneurysm and coronary artery disease.¹³⁾ The revascularization of a major coronary artery with a significant perfusion area and proximal stenosis (>75%) is recommended. Percutaneous coronary intervention (PCI) is another option for coronary revascularization before AAR. However, the risk of cerebral embolism during PCI in the patients with atherosclerotic aortic arch and ascending aorta should not be neglected. In addition, the antiplatelet therapy after PCI enhances the risk of bleeding in the following aortic arch surgery. Significant incidence of restenosis and reintervention could increase the hospital stay and cost.

The importance of intraoperative myocardial protection can not be overemphasized in this surgery. The surgeon should be well prepared for an unexpected prolonged myocardial ischemic time, which is highly associated with early operative death. An AAR may have an unexpected prolonged aortic cross-clamp (ACC) time, especially when the surgeon encounters "difficult distal aortic arch anastomosis" associated with poor accessibility to the anastomosis site through median sternotomy, or fragile or calcified proximal descending aorta, or persistent bleeding from the suture line. Hypertrophied heart caused by longstanding hypertension, as frequently seen in these patients, also demands appropriate intraoperative myocardial protection. Once postoperative myocardial failure has occurred, the placement of intra-aortic balloon pumping would be difficult because of the kinking and atherosclerotic stenosis of the iliac arteries and abdominal aorta with a potential risk of arterial injury or distal arterial embolism. In our recent practice, we have used antegrade and retrograde cold blood cardioplegia to protect myocardium, which has provided satisfactory myocardial protection.

This simultaneous operation is also associated with prolonged myocardial ischemic time and duration of cardiopulmonary bypass, which have been demonstrated as

significant risk factors for early mortality and morbidity in the AAR.^{3,7,10,12)} Kazui and colleagues reported recently that duration of cardiopulmonary bypass longer than 300 minutes is an independent determinant of in-hospital mortality with an odds ratio of 14.2 by analyzing 220 consecutive patients who underwent the total arch replacement with antegrade selective cerebral perfusion.¹⁰⁾ Ueda and associates also demonstrated that the pump time is the most significant risk factor for mortality by a multivariate stepwise logistic analysis of 249 patients who underwent the aortic arch surgery using retrograde cerebral perfusion.⁷⁾ The surgical modalities that are used in an attempt to minimize the duration will be reviewed in the following section.

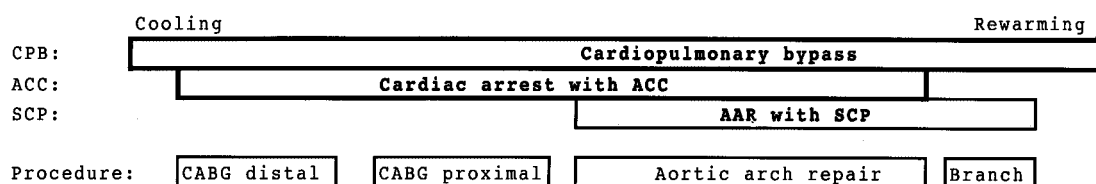
How the Myocardial Ischemic Time and Cardiopulmonary Time can be Minimized?

The combined operation of AAR and CABG has required prolonged duration of myocardial ischemia during AAR (Fig. 1: upper panel). Aortic cross-clamp has been considered mandatory during the establishment of distal coronary anastomosis, and also during the time of AAR. Thus this simultaneous operation is associated with prolonged duration of myocardial ischemia and cardiopulmonary bypass when compared with solo AAR.

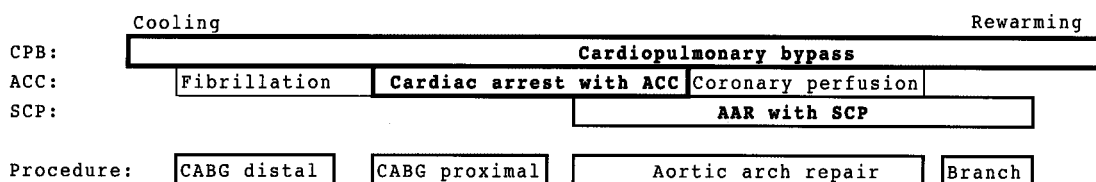
To minimize myocardial ischemic time, several techniques have been employed. Distal coronary artery anastomosis on the fibrillating heart during the period of cooling with cardiopulmonary bypass can decrease the myocardial ischemic time (Fig. 1: middle panel). Surgery on a perfused fibrillating heart with cardiopulmonary bypass was first introduced in the 1950's,¹⁴⁾ and was abandoned in the 1970's because of the advent of cardioplegia. Buckberg et al. showed in animal experiments that oxygen demand during electrically induced ventricular fibrillation is substantial and that subendocardial perfusion is impaired in a fibrillating heart if the heart is distended, or hypertrophied, or when perfusion pressure is low.¹⁵⁾ Although CABG on the perfused fibrillating heart is not technically demanding, the fibrillating motion at the coronary anastomosis and bloody surgical field should be managed. Also a venting of the left ventricle is required to avoid ventricular distension and subendocardial ischemia in the fibrillating heart.

Coronary perfusion method after construction of coronary artery bypass is another option to reduce the myocardial ischemic time during AAR (Fig. 1: middle panel).¹⁶⁾ Through the cardioplegic delivery line that is

1) Conventional (Cardiac arrest with cardioplegia)



2) Perfused fibrillating heart



3) OPCAB

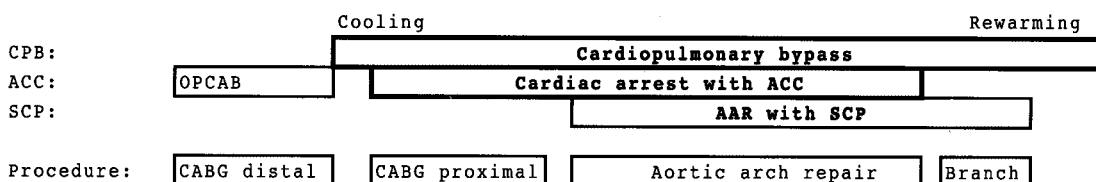


Fig. 1. Time course of the simultaneous aortic arch repair (AAR) and coronary artery bypass grafting (CABG) using the conventional method (upper panel), perfused fibrillating heart (middle panel) and off-pump coronary artery bypass (OPCAB: lower panel).

Each panel presents the sequence of procedure; distal and proximal CABG anastomosis, AAR and arch-branch attachment. These procedures are corresponding to the support methods such as cardiopulmonary bypass (CPB), aortic cross-clamp (ACC) and selective cerebral perfusion (SCP).

anchored to the aortic root, hypothermic oxygenated blood can be delivered to the established bypass grafts and coronary arteries. When AAR is unexpectedly time-consuming, this technique may be a choice as long as the patient has no aortic regurgitation. At this time, left ventricular venting in a perfused fibrillating heart is also mandatory to avoid subendocardial ischemia and the perfusion pressure should be monitored and maintained.

Open stent grafting was introduced for the feasibility of distal anastomosis in ARR. As described by Kato and associates¹⁷⁾ in 1996, the stent graft was introduced through the transected aortic arch, after which the proximal side of the deployed stent graft was fixed to the transected arch. This technique potentially minimizes cardiopulmonary time when compared with the conventional distal aortic arch anastomosis with sutures. Recently, several cases with distal aortic arch aneurysm and coronary artery disease have been reported with successful simultaneous operation of open distal stent technique

and concomitant coronary artery bypass.^{17,18)} Although there are a few drawbacks to the open stent technique such as persistent endoleak, a risk of paraplegia and unknown long-term results, this new technique is worth further clinical trials.

Evolving technology and knowledge have enabled off-pump coronary artery bypass (OPCAB) to be applicable to the routine clinical practice as long as stable hemodynamic is obtained.¹⁹⁾ The application of OPCAB to this simultaneous operation has several advantages. Firstly, this technique can minimize the myocardial ischemic time in comparison with the conventional operation in which all distal coronary anastomosis are constructed on the arrested heart with ACC (Fig. 1: lower panel). Secondly, this technique allows adequate antegrade cardioplegic delivery through the attached bypass grafts to the coronary arteries from the very first time of cardioplegic delivery after ACC, and during the whole period of myocardial ischemia thereafter. Thirdly, this technique can

Table 2. Demographic data of the patient

Group	n	Age	Gender (M/F)	Diseased coronary artery	HT	LVH	OCI
Conventional	22	67 (57-79)	18/4	1.7 (1-4)	10 (45%)	12 (55%)	5 (23%)
OPCAB	23	70 (62-80)	12/1	1.5 (1-3)	11 (85%)	9 (69%)	2 (15%)

OPCAB: off-pump coronary artery bypass, HT: hypertension, LVH: left ventricular hypertrophy, OCI: old cerebral infarction

minimize the duration of cardiopulmonary bypass in comparison with the conventional technique or the operation in which distal coronary anastomosis is established on the perfused fibrillating heart under cardiopulmonary bypass (Fig. 1: compares the duration of cardiopulmonary time in each group).

Review of Our 10-year Experience: Introduction of OPCAB into the Surgical Strategy

Patients

From September 1991 through October 2001, 35 patients underwent the simultaneous operation of aortic arch replacement and coronary artery bypass in Tohoku University Hospital and Fukushima Medical University. They were 30 men and 5 women with an average age of 68 (range: 57-80). The major coronary arteries with significant stenosis (>75%), identified by preoperative coronary angiography, were subjected to simultaneous coronary revascularization. The mean number of diseased coronary arteries was 1.6 (range: 1-4). The mean ejection fraction of the left ventricle was 0.71 (range: 0.48-0.86). Most of the patients had a longstanding history of hypertension. The left ventricular hypertrophy was identified in 21 patients (60%) by echocardiography and/or electrocardiogram. Old cerebral infarction diagnosed by computed tomography or nuclear magnetic resonance imaging was also a frequent comorbidity among these patients.

From 1991 through 1997, CABG was constructed on the arrested heart with cold crystalloid or blood cardioplegia (conventional group: n=22). Since 1998, distal coronary artery anastomosis was constructed on the beating heart before the establishment of cardiopulmonary bypass (OPCAB group: n=13). The demographic data of the patients are listed in Table 2, in which each data in the two groups presented no difference.

Regarding the graft conduit, we prefer free grafts such as radial artery and saphenous vein rather than pedicled internal thoracic artery (ITA) for several reasons. First, the cardioplegic solution can be delivered through the

free grafts during the whole period of myocardial ischemia to achieve better antegrade cardioplegic delivery. Secondly, post-pump hemodynamic instability or hypotension with excessive bleeding is not uncommon in aortic surgery, which deteriorates the blood flow in the arterial grafts with a small caliber such as the ITA and the gastroepiploic artery, resulting in coronary hypoperfusion or vasospasm. Thirdly, the reattachment of the left subclavian artery might affect the left ITA flow at a potential risk of the branched graft kinking. Finally, it is questionable whether the excellent long-term patency of ITA²⁰⁾ is still beneficial for such elderly patients with multiple comorbidities. Our current surgical procedure is introduced as follows.

Off pump CABG

A median sternotomy was used for all patients. A radial artery and/or saphenous vein were harvested as appropriate, using a standard technique. If the proximal left anterior descending artery had a stenotic lesion in young patients, the left ITA was used. Deep pericardial sutures were placed to elevate the left posterior pericardium for lateral and inferior wall exposure.²¹⁾ The Trendelenburg position was employed to obtain an adequate filling of the heart and hemodynamic stability. A table rotation to the right also helped to expose the lateral and inferior wall. Coronary artery stabilization was achieved with an Octopus stabilizer (Medtronic Inc., Minneapolis, MN). No snare was used to avoid the potential late stenosis of the coronary arteries. The coronary artery was opened, followed by introduction of an intraluminal shunt (Clearview®, Medtronic Inc.), achieving a bloodless field with the aid of a CO₂ blower. Coronary artery anastomosis was performed with a running 7-0 monofilament suture.

Aortic arch repair using selective cerebral perfusion

The technique of AAR using antegrade selective cerebral perfusion has previously been described in detail.⁸⁾ Briefly, bilateral subclavian arteries and the left common carotid artery were prepared for perfusion. Cardiopul-

Table 3. Early results of the simultaneous operation of AAR and coronary artery bypass

Group	n	PMI	Stroke	Early death	Hospital death	ACC (min)	CPB (min)	Ventilation (day)	ICU (day)
Conventional	22	4 (18%)	3 (14%)	3 (14%)	6 (27%)	206±44	382±110	7	8
OPCAB	13	0	0	0	1 (8%)	133±26*	245±39*	2	4

OPCAB: off-pump coronary artery bypass, PMI: perioperative myocardial infarction; death within 30 days after operation is included as early death, ACC: aortic cross clamp time, CPB: cardiopulmonary bypass time, ICU: intensive care unit; the duration (minutes) of ACC and CPB are presented as mean±SD; the duration (day) of postoperative ventilatory support and ICU stay are presented as a median value.

monary bypass was established with right atrium drainage and femoral artery perfusion. The femoral artery perfusion was kept below 1 L/min before the establishment of bilateral subclavian perfusion to prevent cerebral embolization by femoral artery perfusion. After bilateral subclavian artery perfusion was initiated, the core body temperature was decreased. An ACC was applied when the heart initiated fibrillation with left atrium venting. The first antegrade cold blood cardioplegia was delivered through the aortic root as well as the attached CABGs. Then proximal anastomosis of the coronary artery graft was established, followed by intermittent cardioplegic delivery through the aortic root every 30 minutes as well as retrograde cardioplegic delivery. We avoided lateral occlusion clamping on the ascending aorta for proximal graft anastomosis because of substantial atheromatous lesion on the ascending aorta. Once the body temperature decreased below 25°C, the left carotid artery was cannulated and perfused. The pressure of the brachiocephalic artery and left common carotid artery were monitored through the perfusion cannulae and kept between 40-60 mmHg.²²⁾ The aortic arch was opened under antegrade selective cerebral perfusion. An open distal anastomosis using a 4-limb branched Dacron graft was performed with a 4-0 polypropylene running suture while the femoral artery perfusion was decreased. The distal body perfusion was reestablished through the branched graft after completion of the distal anastomosis. After the proximal arch anastomosis at the ascending aorta, the arch graft was de-clamped to cease the myocardial ischemia. The left subclavian, left common carotid and brachiocephalic artery were reattached to the branched arch graft in this order with a 5-0 monofilament running suture.

Early surgical outcome

All patients underwent total arch replacement with branched grafts. The average number of coronary artery grafts was 1.7 (range: 1-4). Thirty-nine saphenous veins

and 10 radial arteries and 3 LITA were used for coronary revascularization. Early surgical outcome in the conventional and OPCAB group are listed in Table 3. In the OPCAB group, there was no patient with perioperative myocardial failure, new Q-wave myocardial infarction, or early (<30 days) death. A 74 year-old female with chronic renal failure died of massive gastric bleeding during hemodialysis on the 50th postoperative day, giving an in-hospital mortality rate of 8%. The other 12 patients returned to normal daily life at the first postoperative month. The comparison between the conventional group and OPCAB group clearly demonstrated that involvement of OPCAB in this procedure decreased the duration of myocardial ischemia and cardiopulmonary bypass as well as the length of ventilatory support and the stay in the intensive care unit with satisfactory myocardial protection. These preliminary results suggested that the invasiveness of AAR with moderate hypothermia and antegrade selective cerebral perfusion can be lessened by involvement of OPCAB into the surgical strategy.

Conclusions

The surgical modalities for the combined operation of AAR and CABG have been developed in this decade mainly for better cerebral and myocardial protection, which should be a part of every cardiothoracic surgeon's knowledge. The minimal duration of myocardial ischemia and cardiopulmonary bypass can be achieved with recent surgical techniques. Our preliminary experience demonstrates that OPCAB in this combined operation can be performed feasibly, preventing postoperative myocardial failure followed by satisfactory early outcome. Further less-invasive surgical modalities that enhance the adequate myocardial protection and minimize the adverse effect of cardiopulmonary bypass can improve the outcome of this demanding operation for these elderly patients with aortic arch aneurysm and coronary artery occlusive disease.

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References

1. Yasuda K, Ayabe H, Ide H, Kitamura S. Thoracic and cardiovascular surgery in Japan during 1999: annual report by the Japanese Association for Thoracic Surgery. *Jpn J Thorac Cardiovasc Surg* 2001; **49**: 528–39.
2. Crawford ES, Svensson LG, Coselli JS, Safi HJ, Hess KR. Surgical treatment of aneurysm and/or dissection of the ascending aorta, transverse aortic arch, and ascending aorta and transverse aortic arch. *J Thorac Cardiovasc Surg* 1989; **98**: 659–74.
3. Ehrlich MP, Ergin MA, McCullough JN, et al. Predictors of adverse outcome and transient neurologic dysfunction after ascending aorta/hemiarch replacement. *Ann Thorac Surg* 2000; **69**: 1755–63.
4. Svensson LG, Crawford ES, Hess KR, et al. Deep hypothermia with circulatory arrest. Determinants of stroke and early mortality in 656 patients. *J Thorac Cardiovasc Surg* 1993; **106**: 19–31.
5. Coselli JC, Buket S, Djukanovic B. Aortic arch operation: current treatment and results. *Ann Thorac Surg* 1995; **59**: 19–27.
6. Okita Y, Takamoto S, Ando M, Morota T, Matukawa R, Kawashima Y. Mortality and cerebral outcome in patients who underwent aortic arch operations using deep hypothermic circulatory arrest with retrograde cerebral perfusion: no relation of early death, stroke and delirium to the duration of circulatory arrest. *J Thorac Cardiovasc Surg* 1998; **115**: 129–38.
7. Ueda Y, Okita Y, Aomi S, Koyanagi H, Takamoto S. Retrograde cerebral perfusion for aortic arch surgery: analysis of risk factors. *Ann Thorac Surg* 1999; **67**: 1879–82.
8. Tabayashi K, Ohmi M, Togo T, et al. Aortic arch aneurysm repair using selective cerebral perfusion. *Ann Thorac Surg* 1994; **57**: 1305–10.
9. Hayashi J, Eguchi S, Yasuda K, et al. Aortic arch operation using selective cerebral perfusion for nondissecting thoracic aneurysm. *Ann Thorac Surg* 1997; **63**: 88–92.
10. Kazui T, Washiyama N, Muhammad BAH, et al. Total arch replacement using aortic arch branched grafts with the aid of antegrade selective cerebral perfusion. *Ann Thorac Surg* 2000; **70**: 3–9.
11. Yamashiro S, Sakata R, Nakayama Y, Ura M, Arai Y, Morishima Y. One-stage thoracic aortic aneurysm treatment and coronary artery bypass grafting. *Jpn J Thorac Cardiovasc Surg* 2001; **49**: 236–43.
12. Sadahiro M, Niibori K, Tsuru Y, et al. Risk factor analysis of early and late operative mortality after ascending aorta or aortic arch replacement. *Ann Thorac Cardiovasc Surg* 1997; **3**: 39–46.
13. Ueda T, Shimizu H, Shin H, et al. Detection and management of concomitant coronary artery disease in patients undergoing thoracic aortic surgery. *Jpn J Thorac Cardiovasc Surg* 2001; **49**: 424–30.
14. Senning A. Ventricular fibrillation during extracorporeal circulation. *Acta Chir Scand* 1951; **171**: 8–72.
15. Buckburg GD, Fixler DE, Archie JP, Hoffman JIE. Experimental subendocardial ischemia in dogs with normal coronary arteries. *Circ Res* 1972; **30**: 67–81.
16. Sadahiro M, Togo T, Iguchi A, Akasaka J, Tabayashi K. Concomitant replacement of the complete aortic arch with coronary artery bypass grafting and iliofemoral bypass grafting by means of selective cerebral and coronary perfusion technique (English abstract). *Kyobu-geka* 1995; **48**: 347–53.
17. Kato M, Ohnishi K, Kaneko M, et al. New graft-implanting method for thoracic aortic aneurysm or dissection with a stented graft. *Circulation* 1996; **94**: II 188–93.
18. Kochi K, Sueda T, Shibamura H, Orihashi K, Matuura Y. Stent-grafting to descending thoracic aorta during coronary artery bypass grafting. *Ann Thorac Surg* 1999; **68**: 1418–20.
19. Buffolo E, de Andrade CS, Branco JN, Teles CA, Aguiar LF, Gomes WJ. Coronary artery bypass grafting without cardiopulmonary bypass. *Ann Thorac Surg* 1996; **61**: 63–6.
20. Loop FD, Lytle BW, Cosgrove DM, et al. Influence of the internal-mammary-artery graft on 10-year survival and other cardiac events. *N Eng J Med* 1986; **314**: 1–6.
21. Bergsland J, Karamanoukian HL, Soltoski PR, Salerno TA. “Single suture” for circumflex exposure in off-pump coronary artery bypass grafting. *Ann Thorac Surg* 1999; **68**: 1428–30.
22. Sadahiro M, Haneda K, Mohri H. Experimental study of cerebral autoregulation during cardiopulmonary bypass with or without pulsatile perfusion. *J Thorac Cardiovasc Surg* 1994; **108**: 446–54.