Original Article

Central Arterial Cannulation and the Arch First Method for Aortic Arch Aneurysm Repair

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Background: We investigated whether the axillary artery or ascending aorta cannulation combined with the arch first method decreases the risk of stroke during total arch replacement.
Patients and Methods: From January 2002 to January 2006, 35 total arch replacements were performed with the arch first method and central arterial cannulation. The mean age was 66±10 years. The cannulation sites were the axillary artery in 19 and the ascending aorta in 16. The arch first method (a short period of deep hypothermic circulatory arrest with retrograde cerebral perfusion and then subsequent antegrade cerebral perfusion) was used in all patients.
Results: The mean retrograde cerebral perfusion time was 29±7 min. The incidence of the permanent neurological dysfunction related to the surgical procedures was 2.9% (1/35). Hospital mortality was 5.7% of patients (2/35). There was no difference in the operative outcome between the 2 arterial inflow sites.
Conclusion: At the time of total arch replacement, the use of central arterial cannulation and the arch first method are effective methods for preventing permanent brain injury. Cannulation of the ascending aortic using Dispersion cannula perfusing toward the aortic valve is considered to be a safe and favorable method for central arterial cannulation. (Ann Thorac Cardiovasc Surg 2006; 12: 404–11)

Key words: aortic aneurysm, cerebral protection, cardiopulmonary bypass, complication, stroke

Introduction

Brain injury is a one of the major causes of morbidity and mortality after an aortic arch aneurysm operation. The risk factors for perioperative stroke are a pre-existing cerebral or carotid occlusive lesion, an atheromatous embolism occurring due to manipulation of aorta, a dislodgement of plaque under retrograde flow by femoral artery cannulation, and the cerebral protection method used.[1] Various modalities have been used to prevent brain complications.

Since 2002, we have performed aortic arch repair using central arterial cannulation (the ascending aorta or axillary artery for the cannulation site), and the arch first method (a short period of deep hypothermic circulatory arrest with retrograde cerebral perfusion (RCP) and then subsequent selective antegrade cerebral perfusion (SCP)). This was used to avoid thromboembolism during surgery and to shorten the circulatory arrest time (CA). We herein report on our experience in 35 patients.

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Patients and Methods

From January 2002 to January 2006, 35 patients underwent total arch replacement by either the arch first method using the axillary artery or ascending aorta cannulation for cardiopulmonary bypass (CPB). The mean age of the 26 males and 9 females was 66±10 years. The preoperative states of all cases are shown in Table 1. The preoperative diagnosis was classified as a true aneurysm in 27 (77%), and an aortic dissection in 8 (23%). Six (17%) patients who underwent emergent operation due to a rup-

Table 1. Preoperative clinical characteristics

	Arterial inflow site			
	Overall (n=35)	Aorta (n=16)	Axillary (n=19)	*p*-value
Sex (male)	26	11	15	0.8
Age (y)	66±10	66±9	65±11	0.6
Emergent case	6	3	3	>0.99
Aortic pathology				0.2
True aneurysm (rupture)	27 (2)	14 (2)	13 (0)	
Acute dissection	3	0	3	
Chronic dissection (rupture)	5 (1)	2 (1)	3 (0)	
CAD	14	4	10	0.1
COPD	3	2	1	0.6
Hypertension	31	14	17	>0.99
Renal dysfunction[a]	4	0	4	0.1
Cererbrovascular/carotid disease	4	2	2	>0.99
ASO	1	0	1	>0.99
AAA (postoperative state)	9 (6)	4 (2)	5 (4)	>0.99
Diabetes	3	1	2	>0.99
Previous cardiac surgery	2	0	2	0.5

[a], serum creatinine >2.0 mg/dl.
y, years; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; ASO, arteriosclerosis oblitelans; AAA, abdominal aortic aneurysm.

ture of the aneurysm or acute aortic dissection were included. The preoperative risk factors included: hypertension in 31 (88.6%) patients, coronary artery disease (CAD) in 14 (40.0%), renal dysfunction (serum creatinine >2.0 mg/dl) in 4 (11.4%), diabetes in 3 (8.6%), and chronic obstructive pulmonary disease (COPD) in 3 (8.6%). Two patients had previously undergone surgery requiring a sternotomy. Aortic root replacement was performed in 2 (5.7%) patients, coronary artery bypass grafting (CABG) in 11 (31.4%) patients, aortic valve replacement in 1 (2.9%) patient, and the Dor procedure in 1 (2.9%) patient.

The operation was performed through a median sternotomy in all cases. In 2 cases we added a left intercostal thoracotomy. The cannulation site for arterial return was selected based on the findings of a preoperative computed tomography (CT) scan and an intraoperative epiaortic echo scan. When an atheromatous plaque or an ulceration of the ascending aorta was detected, or when the ascending aorta was dissected, a right axillary cannulation was employed. Otherwise the ascending aorta was cannulated for arterial return. According to the methods of Grooters, we inserted a Dispersion cannula (Edwards Lifesciences Inc., Midvale, UT, USA), so that the flow would go to the aortic root (Fig. 1A).[2] The right axillary artery was cannulated either directly using a 20 French size cannula (DLP elongated one piece arterial cannula; Medtronic Inc., Minneapolis, MN, USA) or via a graft (Fig. 1B). After bicaval cannulation, core cooling was started with a standard heart-lung machine using a membrane oxygenator. Myocardial protection went achieved by retrograde continuous perfusion of cold blood cardioplegic solution. The arch first method (a short period of deep hypothermic circulatory arrest with RCP and then subsequent SCP) was employed for reconstruction of the aortic arch (Fig. 2). Circulatory arrest with retrograde cerebral perfusion was started at the nasopharyngeal temperature of 18˚C. During circulatory arrest, the arch vessels were transected and reconstructed using an arch graft with 4 branches (Vascutek Gelweave woven graft; Terumo Corp., Renfrewshire, Scotland, UK). After the completion of each arch vessel reconstruction. Both ends of the graft were clamped and an antegrade cerebral perfusion was started through the side branch of the arch graft or axillary artery. A distal anastomosis was performed using another graft with a running suture and Teflon felt strip reinforced on the adventia. Debris and air were washed out from the descending aorta after completion of the distal anastomosis. This was performed by perfusing blood from the femoral artery cannula inserted before starting the CPB. After the approximation of the 2 grafts, antegrade systemic perfusion was restarted through the side branch of the arch graft and then full rewarming was started. Finally, we performed proximal anastomo-

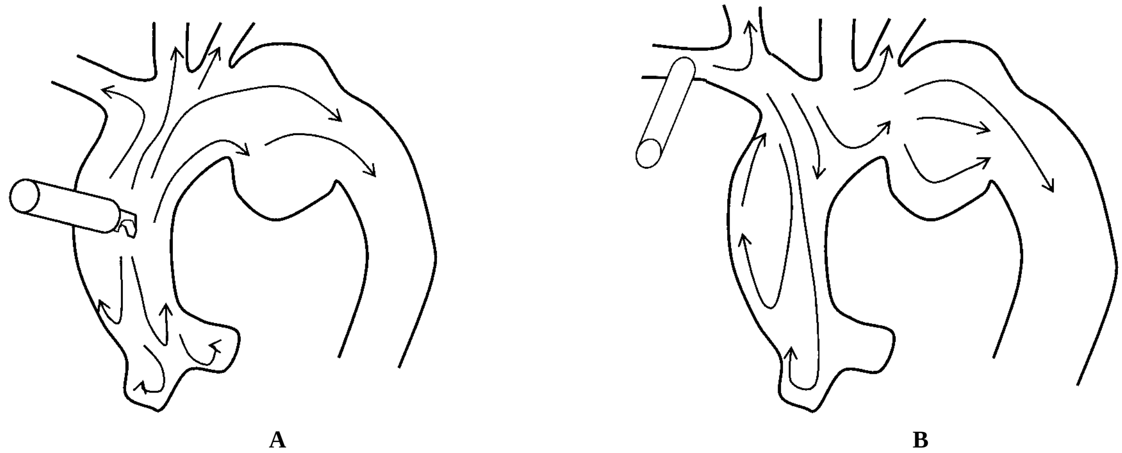

Fig. 1. Two different methods of central arterial cannulation.
A: Ascending aortic cannulation using Dispersion cannula toward the aortic valve.
B: Axillary arterial cannulation.

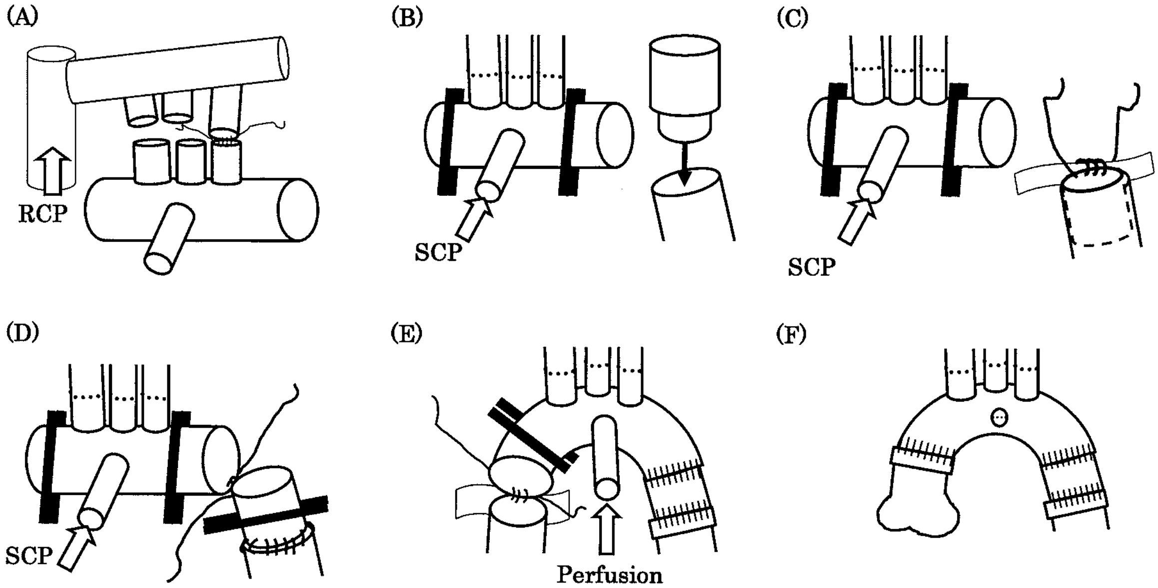

Fig. 2. Arch first method for replacement of the aortic.
A: The arch branches are reconstructed using graft with 4 branches under the circulatory arrest with RCP.
B: After the completion of arch vessel reconstruction, SCP can be started.
C: Distal arch is transected. Another tube graft whose proximal end is inverted into the distal part of the graft. The inverted graft is placed in the descending aorta and sutured in position.
D: The tube graft is withdrawn from the distal aorta. The proximal end of the tube graft is anastomosed end-to-end to the distal end of the arch graft.
E, F: Systemic antegrade perfusion is restarted from the side graft with the proximal arch graft clamped. The proximal anastomosis is thereafter completed.
RCP, retrograde cerebral perfusion; SCP, selective antegrade cerebral perfusion.

Table 2. Operative characteristics and outcome

	Arterial inflow site			
	Overall (n=35)	Aorta (n=16)	Axillary (n=19)	*p*-value
Arterial cannula				*p*<0.0001
Dispersion 21 Fr. or 24 Fr.	16	16	0	
Elongated 20 Fr.	12	0	12	
Tube graft 8 mm	7	0	7	
Concomitant procedure				
CABG	11 (31.4%)	3 (18.8%)	8 (42.1%)	0.1
Aortic root replacement	2 (5.7%)	0	2 (10.5%)	0.5
AVR	1 (2.9%)	1 (6.3%)	0	0.5
Dor operation	1 (2.9%)	0	1 (5.3%)	>0.99
Pulmonary vein isolation	1 (2.9%)	1 (6.3%)	0	0.5
Operative time (min)	500±92	500±92	528±80	0.05
CPB time (min)	240±53	237±72	242±39	0.3
RCP time (min)	29±7	29±7	30±7	0.07
CA time of lower half body (min)	90±21	90±21	88±19	0.7
Cardiac arrest time (min)	151±41	151±45	151±41	0.5
Perioperative myocardial infarction[a]	0	0	0	>0.99
IABP	2 (5.7%)	1 (6.3%)	1 (5.3%)	>0.99
Bleeding[b]	1 (2.9%)	1 (6.3%)	0	0.5
Respiratory failure[c]	7 (20.0%)	0	7 (36.8%)	0.009
Renal failure[d]	5 (14.3%)	2 (12.5%)	3 (15.8%)	>0.99
Brachial plexus injury	1 (2.9%)	0	1 (5.3%)	>0.99
Hospital death	2 (5.7%)	1 (6.3%)	1 (5.3%)	>0.99

[a], new Q wave or peak CK-MB >100 ng/ml); [b], performed re-thoracotomy for hemostasis; [c], intubation > 72 hours; [d], requirement for dialysis.

Fr., French size (cannula); CABG, coronary artery bypass grafting; AVR, aortic valve replacement; CPB, cardiopulmonary bypass; RCP, retrograde cerebral perfusion; CA, circulatory arrest; IABP, intraaortic balloon pumping.

sis with a running suture under the perfusion from side branch of the graft, and completed the reconstruction of the aortic arch.

Statistical analysis

Univariate analysis for risk factors of the neurological dysfunction was carried out. The preoperative variables used were age, sex, etiology (dissection or not), cerebrovascular disease, CAD, renal dysfunction (serum creatinine >1.8 mg/dl), COPD, hypertension, diabetes and hyperlipidemia. The intraopereative or postoperative variables were emergent operation, CABG, the use of mechanical valve, Bentall operation, arterial return (axillary or aorta), operative time, RCP time, duration of mechanical ventilation, and postoperative renal failure. The chi-square test was used to compare categorical variables when the smallest number of individuals in a category of less than 5. The Fisher's exact test was used otherwise. Continuous variables were compared using the Mann-Whitney U-test.

Results

We were able to perform ascending aorta cannulation in 16 (45.7%) patients. In the other 19 (54.3%) patients, we performed right axillary artery cannulation. The reasons for giving up ascending aortic cannulation were thick intima or calcification of the aortic wall in 11, aortic dissection in 5; redo surgery in 2; and large aneurysm in 1 patient. Direct cannulation was performed in 12 (34.3%) patients, and cannulation via a graft in 7 (20%) patients. There were no significant differences between the 2 different groups of cannulation sites in term of age, sex, aortic pathology, preoperative comorbidity (Table 1), and concomitant procedures (Table 2). As depicted in Table 2, no differences were found in aortic cross-clamp time, RCP time, CA time and operative time between the 2 groups.

There was no difference in incidence of postoperative neurological dysfunction between the 2 groups (Table 3). A transient neurological dysfunction, defined as postoperative delirium or convulsion with negative CT results

Table 3. Postoperative brain dysfunction

	Arterial inflow site			
	Overall (n=35)	Aorta (n=16)	Axillary (n=19)	*p*-value
Transient neurological dysfunction	10 (28.6%)	4 (25.0%)	6 (31.6%)	0.7
Delirium	9	4	5	>0.99
Convulsion	2	0	2	0.5
Permanent neurological dysfunction	2 (5.7%)	1 (6.3%)	1 (5.3%)	>0.99
Cerebral infarction	1 (2.9%)	0	1	>0.99
Cerebral hemorrhage	1 (2.9%)*	1*	0	0.5

*, late onset, anticoagulant related complication.

and a complete resolution of symptoms before discharge, was observed in 9 patients (25.7%). A permanent neurological dysfunction, defined as permanent neurological deficits with localizing neurological signs and a corresponding new defect observed on CT scanning, was noted in 2 patients (5.7%). One patient suffered a brain embolism, while another had a brain hemorrhage. The first patient was a 68-year-old male with an atherosclerotic distal arch aneurysm, triple vessel coronary heart disease, a thoracoabdominal aortic aneurysm, multiple bilateral carotid artery plaque, and chronic renal failure on hemodialysis. He underwent a total arch replacement with RCP of 27 min and triple CABGs. Right axillary arterial cannulation was employed and the total bypass time was 301 min. His postoperative course was complicated by a large cerebral infarction of the bilateral middle cerebral artery (MCA) area. He died due to sepsis accompanied with pneumonia on postoperative day 17. The second patient was a 72-year-old female who had Annulo-aortic ectasia with severe aortic regurgitation, arch aneurysm, and multiple myeloma. She underwent aortic root replacement and a total arch replacement with RCP of 24 min. Ascending aortic cannulation was employed and the total CPB time was 224 min. She woke up and was extubated 7 hours after the operation. Her recovery was uncomplicated until the sudden onset of right hemiparesis on the 14th postoperative day. CT scanning revealed a high density area in the left parietal lobe and cerebellum. She was discharged after 3 months of rehabilitation. The cause of cerebral hemorrhage was Warfarin anticoagulation for the artificial heart valve, and did not relate to the operative procedures. Finally, the incidence of permanent neurological dysfunction relating to the surgical procedures was 2.9% (1/35). The duration of the RCP was not different in patients with or without postoperative neurological dysfunction. Univariate analysis of risk factors for postoperative neurological dysfunction failed to show any significant preoperative or intraopereative factors (Table 4).

Respiratory insufficiency, defined as postoperative artificial ventilation of over 72 hours, was seen in 7 patients (20%). High incidence of respiratory failure associated with longer operation time and RCP time was observed in patients with axillary arterial cannulation. Renal failure which required postoperative continuous hemodiafiltration (CHDF) was observed in 5 patients (14.3%). There was 1 case of ipsilateral brachial plexus injury resulting in permanent weakness in the right hand as a complication of axillary artery cannulation.

Hospital mortality was noted in 2 patients (5.7%). The causes of death were myonephropathic metabolic syndrome after surgery and sepsis accompanied with post operative stroke and pneumonia (Table 2). The first patient was a 73-year-old male who had a ruptured chronic aortic dissection. He underwent a total replacement of the arch and proximal descending thoracic aorta with RCP of 19 min. Ascending aortic cannulation was employed and the total CPB time was 237 min. His postoperative course was complicated by acute renal failure due to rhabdomyolysis. He died due to multi organ failure on postoperative day 3. Another patient was a 68-year-old male. He had a large cerebral infarction postoperatively, and died owing to sepsis accompanied with pneumonia on postoperative day 17.

Comment

The incidence of postoperative disorders of the central nervous system in an aortic arch aneurysm operation varies depending on the cerebral protection method and the arterial cannulation site for CPB. However, it ranges from 4 to 11% based on a recent report.[1,3–5] During an operation for a thoracic aortic aneurysm under profound hypo-

Table 4. Univariate analysis of risk factors for postoperative neurological dysfunction in 35 patients

Variable	Number of patients	Postoperative neurological dysfunction	p-value
Sex			0.70
Male	26	10	
Female	9	2	
Age			0.29
Age<70 y	22	10	
Age≥70 y	13	2	
Aortic dissection			0.47
Yes	8	4	
No	27	8	
Cerebrovascular disease			0.64
Yes	4	2	
No	31	10	
CAD			>0.99
Yes	14	5	
No	21	7	
Renal dysfunction			0.096
SCrea ≥1.8 mg/dl	5	5	
SCrea <1.8 mg/dl	30	7	
COPD			>0.99
Yes	3	1	
No	32	11	
Hypertension			>0.99
Yes	31	11	
No	4	1	
Emergent operation			0.66
Yes	6	1	
No	29	11	
CABG			0.73
Yes	11	5	
No	24	7	
Mechanical valve			0.59
Yes	2	2	
No	33	10	
Bentall operation			0.27
Yes	2	2	
No	33	10	
Arterial return			>0.99
Aorta	16	6	
Axillary	19	6	
Operative time			0.16
<480 min	15	3	
≥480 min	20	9	
RCP time			0.52
<30 min	19	5	
≥30 min	16	7	
Ventilator			0.44
<72 hours	7	4	
≥72 hours	28	8	

y, years; CAD, coronary artery disease; SCrea, serum creatinine; COPD, chronic obstructive pulmonary disease; CABG, coronary artery bypass grafting; RCP, retrograde cerebral perfusion.

thermic CA, the main cause of permanent neurological disorders is an intraaortic atheromatous embolus. Such an embolism occurs due to a dislodgement of an atheroma of the aortic wall as a result of either arterial cannulation or the manipulation of an aorta.[5] Because perfusion by the femoral artery cannulation is a retrograde flow, it is very likely that atheroma of the descending thoracic aorta or abdominal aorta may be isolated, thus developing into a cerebral embolism.[1)]

The cannulation of the ascending aorta for the arterial return of CPB provides antegrade perfusion thereby decreasing the embolic risk. When the ascending aorta is unsuitable for cannulation, in a case demonstrating either atherosclerosis or a dissection of the ascending aorta, axillary arterial cannulation is alternative method.[6)] However, either a dissection or injury of the vascular wall and a brachial plexus disorder may sometimes occur as a complication of axillary arterial cannulation. There are 2 methods for performing axillary artery cannulation. Namely, cannulating the artery directly or via a graft. In the former, there are some problems when the arterial wall is fragile, or an appropriately sized cannula can not be properly inserted. Regarding vascular injury, we did not experience any case that could not be treated with this method in this study group even when the artery appeared fragile. In addition, we could insert a 20 Fr. cannula in all cases and were able to secure a sufficient systemic perfusion flow rate. Also, because there is low risk of bleeding, we performed the direct insertion method of choice except first 5 cases. However, we experienced brachial plexus injury in 1 patient. This complication commonly occurs when preparing the lateral portion of the axillary artery and we try to prepare the medial portion as much as possible now in order to avoid this complication afterwards.[7)]

Postoperative cerebral infarction due to operative procedures occurred in only 1 case in this study (2.9%). He had renal insufficiency under hemodialysis, and severe systemic arterial sclerosis with intimal thickening of the ascending aorta and atherosclerosis of the aortic arch. As a result, a total arch replacement and CABG were performed under CPB with axillary artery cannulation. The blood flow from the brachiocephalic trunk face with the lesser curvature side of the aortic arch in a case of arterial return via axillary arterial cannulation. In this patient, the atheroma of this lesion was thought to have scattered and caused a cerebral infarction. The sandblasting effect of the high velocity jet of blood that exits the aortic cannula and strikes a friable atherosclerosis within the aortic arch has been recognized as a frequent source of perioperative stroke. Grooters et al. reported a new technique of perfusion toward the aortic valve using a newly designed "Dispersion" cannula which eliminates the sandblasting effect of the perfusion cannula into the aortic arch, thereby reducing the rate of embolic stroke.[2,8)] There was no postoperative cerebral embolism in the patient who used the method of Grooters et al. in our study. Therefore, the ascending aortic cannulation using this technique is recommended if the ascending aorta does not have an atherosclerotic lesion or dissection.

Regarding the cerebral protection method, 2 different methods, namely deep hypothermic circulatory arrest with or without retrograde cerebral perfusion, and the SCP method, were performed, and the results of each have been reported.[3–5)] Although there is a limitation of time when using the RCP method, this procedure is technically simpler and easier to perform than the SCP method. In addition, there is no embolic risk by atheromatous plaque dislodgement at the cannulation into the arch vessels, and the retrograde blood flow prevents such air and debris from falling into the arch vessels. When using the arch first method, the reconstruction of the arch vessels can thus be achieved using retrograde brain perfusion for an average of 30 min. Because we can perform antegrade cerebral perfusion by arterial return into an arch graft afterwards, we think that the arch first method is a simple and useful method to supplement the weak points of these 2 methods.[9)] This study did not show any permanent neurological dysfunction due to the RCP, but transient neurological dysfunctions, such as postoperative delirium or convulsion did occasionally occur. A correlation between the cerebral ischemia time and transient neurological dysfunction has been reported.[5)] Delirium does not contribute to hospital death, but it is one disadvantage of the RCP or CA. New methods to shorten the cerebral ischemic time are needed to be developed. Trifurcated graft implantation combined with hypothermic circulatory arrest and selective cerebral perfusion described by Spielvogel et al. are one solution for this problem.[10)]

The average CA time of the lower part of the body was 90 min which was a little too long. This is a disadvantage of the arch first method, but we did not observed any correlation between the postoperative SCrea peak value and CA time. However, hemofiltration or hemodialysis has to be transiently performed in patients with the renal dysfunction preoperatively. In such cases, we should shorten the CA time of a lower part of the body using distal aortic perfusion during arch reconstruction.[11)]

The present study has several limitations. First, because the study was retrospective and not controlled, we could not compare our central arterial cannulation method with the femoral arterial cannulation or standard ascending aortic cannulation as a control. Second, because the number of patients was limited, the various clinical parameters concerning the onset of brain injury could not be identified. These points should be re-evaluated in a future study.

Conclusion

Our results suggest that both central arterial cannulation and the arch first method are simple and favorable methods for preventing permanent brain injury at the time of total arch replacement. The cannulation of the ascending aortic using Dispersion cannula perfusing toward the aortic valve is also considered to be an alternative method for performing a central arterial cannulation if the ascending aorta is suitable for cannulation.

References

1. Svensson LG, Blackstone EH, Rajeswaran J, et al. Does the arterial cannulation site for circulatory arrest influence stroke risk? *Ann Thorac Surg* 2004; **78**: 1274–84.
2. Grooters RK, Thieman KC, Schneider RF, Nelson MG. Assessment of perfusion toward the aortic valve using the new dispersion aortic cannula during coronary artery bypass surgery. *Tex Heart Inst J* 2000; **27**: 361–5.
3. Kazui T, Washiyama N, Muhammad BA, Terada H, Yamashita K, Takinami M. Improved results of atherosclerotic arch aneurysm operations with a refined technique. *J Thorac Cardiovasc Surg* 2001; **121**: 491–9.
4. Okita Y, Minatoya K, Tagusari O, Ando M, Nagatsuka K, Kitamura S. Prospective comparative study of brain protection in total aortic arch replacement: deep hypothermic circulatory arrest with retrograde cerebral perfusion or selective antegrade cerebral perfusion. *Ann Thorac Surg* 2001; **72**: 72–9.
5. Ergin MA, Galla JD, Lansman L, Quintana C, Bodian C, Griepp RB. Hypothermic circulatory arrest in operations on the thoracic aorta. Determinants of operative mortality and neurologic outcome. *J Thorac Cardiovasc Surg* 1994; **107**: 788–99.
6. Strauch JT, Spielvogel D, Lauten A, et al. Axillary artery cannulation: routine use in ascending aorta and aortic arch replacement. *Ann Thorac Surg* 2004; **78**: 103–8.
7. Baribeau YR, Westbrook BM, Charlesworth DC, Maloney CT. Arterial inflow via an axillary artery graft for the severely atheromatous aorta. *Ann Thorac Surg* 1998; **66**: 33–7.
8. Grooters RK, Ver Steeg DA, Stewart MJ, Thieman KC, Schneider RF. Echocardiographic comparison of the standard end-hole cannula, the soft-flow cannula, and the dispersion cannula during perfusion into the aortic arch. *Ann Thorac Surg* 2003; **75**: 1919–23.
9. Nishimura M, Ohtake S, Sawa Y, et al. Arch-first technique for aortic arch aneurysm repair through median sternotomy. *Ann Thorac Surg* 2002; **74**: 1264–6.
10. Spielvogel D, Mathur MN, Lansman SL, Griepp RB. Aortic arch reconstruction using a trifurcated graft. *Ann Thorac Surg* 2003; **75**: 1034–6.
11. Klodell CT, Hess PJ, Beaver TM, Clark D, Martin TD. Distal aortic perfusion during aortic arch reconstruction: another tool for the aortic surgeon. *Ann Thorac Surg* 2004; **78**: 2196–8.