Original Article

Total Arch Replacement Using Bilateral Axillary Antegrade Selective Cerebral Perfusion

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Objective: The prevention of cerebral injury is an important consideration during the repair of an aortic arch aneurysm, and this is a major goal of cerebral protection techniques. We describe extended thoracic aortic aneurysms treated by use of our current surgical strategy.
Patients and methods: From January 2001 to June 2008, a total of 17 patients (12 men and 5 women; mean age 67.3 ± 7.3 yrs) underwent total arch replacement using bilateral axillary arterial perfusion. Six and 11 had nondissecting and dissecting aneurysms, respectively. Four patients (23.5%) with an impending ruptured aneurysm of the arch aorta or acute type A dissection underwent emergency surgery. We used bilateral axillary arteries for systemic as well as selective cerebral perfusion during the procedures.
Results: One patient died in the hospital (mortality rate, 5.9%) because of multiple organ failure. Mechanical ventilation was required after surgery for 4.6 ± 3.1 days. Permanent neurological dysfunction did not arise in this series. Although prolonged mechanical ventilation support was necessary, all patients recovered uneventfully from the procedures.
Conclusion: We consider that median sternotomy, along with the left anterolateral thoracotomy approach and perfusion from the bilateral axillary arteries, illustrates the safety of the method. Moreover, our results suggested that perfusion from the bilateral axillary arteries can help to prevent cerebral damage. (Ann Thorac Cardiovasc Surg 2010; 16: 259–263)

Key words: aortic arch aneurysm, deep hypothermic circulatory arrest, selective cerebral perfusion, axillary artery

Introduction

Despite advances in surgical techniques, such as management of anesthesia and cardiopulmonary bypass (CPB),[1,2] brain injury after aortic arch surgery remains an important source of morbidity and mortality because of the advanced age of the patients and the presence of severe comorbidities.[3]

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We describe extended aortic replacement using our current strategy.

Patients and Methods

From January 2001 to June 2008, 17 consecutive patients at our institution with extended thoracic aortic aneurysms underwent total replacement of the arch and descending aorta using bilateral axillary arterial perfusion and an 8-mm graft. Table 1 shows the characteristics of the 12 male and 5 female patients (mean age 67.3 ± 7.3 yrs; range 56–80 yrs). Five had atherosclerotic distal arch aneurysms, 5 had chronic type A dissection after graft replacement of the ascending aorta or aortic arch, 3 had chronic type B dissection, 3 had acute type A dissection, and 1 had infectious arch aneurysms. Four of the 17 patients (23.5%) each had impending ruptured infectious aneurysms of the arch aorta and acute type A dissection that required emergency surgery. Coronary angiography was also performed before surgery for all patients except for those in emergency. Five patients had undergone a previous graft replacement of the ascending aorta or arch aorta, 1 had aortic valve replacement (AVR), and 1 had a coronary artery bypass graft (CABG). One patient underwent concomitant cardiac procedures, AVR and mitral valve replacement (MVR) with CABG. In this series, there were 3 acute type A dissection cases. Two were retrograde whose entry was located on descending aorta, and 1 was a reoperative situation for a previous cardiac operation, an AVR; adhesion resulting from previous surgeries can be moderate or severe. These 3 cases required extensive replacement of the arch and descending aorta. In the 3 chronic type B dissection cases, in which the distal arch was enlarged in all, including the origin of the left subclavian artery. They also required extensive replacement of the arch and descending aorta.

Table 1. Characteristics of patients

Total number	17
Age (y)	67.3 ± 7.3 (range, 56–83)
Gender (M/F)	12/5
Diagnosis	
Atherosclerotic	5 (29.4%)
Chronic type B dissection	3 (17.6%)
Chronic type A dissection	5 (29.4%)
Acute type A dissection	3 (17.6%)
Infectious	1 (5.9%)
Emergency	4 (23.5%)
Impending rupture	1
Acute type A dissection	3
Operative history	8 (47.1%)
Ascending aortic replacement	5
AVR	1
CABG	1
Underlying disorders	
HT	14 (82.4%)
DM	6 (35.3%)
HL	12 (70.6%)
Concomitant procedures	1 (5.9%)
AVR+MVR+CABG	1

M, male; F, female; AVR, aortic valve replacement; CABG, coronary artery bypass grafting; HT, hypertension; DM, diabetes mellitus; HL, hyperlipidemia; MVR, mitral valve replacement. M, male; F, female; AVR, aortic valve replacement; CABG, coronary artery bypass grafting; HT, hypertension; DM, diabetes mellitus; HL, hyperlipidemia; MVR, mitral valve replacement.

Surgical techniques

The patients were endotracheally intubated with a double-lumen tube to deflate the lungs and then positioned on an operating table with the chest rotated 60° from the supine toward the right. A 5- to 6-cm transverse skin incision was made before the median sternotomy at about 1 cm below the middle and lateral parts of the clavicle. Bilateral axillary arteries with or without the right femoral artery (FA) served as the perfusion site for all patients. A graft 8 mm in diameter was anastomosed to the bilateral axillary arteries for systemic arterial cannulation after systemic heparinization. These grafts were used for antegrade selective cerebral perfusion (SCP) after deep hypothermic circulatory arrest (HCA). The heart, ascending aorta, aortic arch, and arch vessels were exposed through a median sternotomy with a sternum transection plus a left fourth intercostal thoracotomy (the “door-open” method). During the operation, the combined approach (median sternotomy with left anterolateral thoracotomy) was used because the predicted distal anastomosis level was below the sixth vertebra. This approach provided a good view of the entire heart as well as of the entire aorta, and it enabled distal anastomosis under cross-clamping with distal perfusion to prevent visceral ischemia. When the patient’s rectal temperature reached 20°C, the systemic circulation was arrested and the aorta was opened. Antegrade SCP was established through vascular grafts anastomosed to the bilateral axillary arteries and a perfusion catheter placed directly into the left carotid artery. The temperature of antegrade SCP was maintained at 15°C, and cerebral perfusion was established at a flow rate of 10 to 15 ml/kg/min, using a double roller pump separate from the systemic circulation. Bilateral radial arteries and left carotid artery stump pressure were monitored and controlled from 40 to 50 mmHg by regulating SCP flow. Perioperative blood flow through the middle cerebral arteries was monitored continuously with bilateral transcranial Doppler (Viasys Inc., Conshocken, PA, USA). Moreover, cerebral oxygen saturation was monitored using an INVOS® Cerebral/Somatic Oximeter (Somanetics Corp., Troy, MI, USA). Figure 1 shows a schema of the surgical approach and cerebral protection. Distal anastomosis proceeded under cross-clamping of the distal descending aorta with distal perfusion through FA in 8 patients to prevent visceral ischemia. The temperature of distal perfusion from the femoral artery was maintained at 20°C. The remaining 9 patients underwent open distal anastomosis. After completing these procedures, the graft was drawn anteriorly into the isolated residual

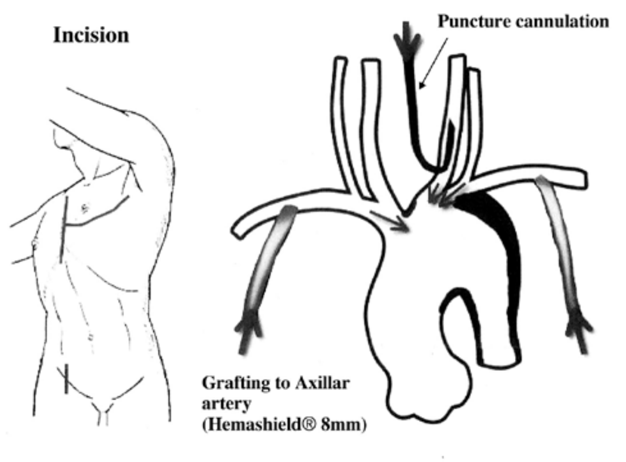

Fig. 1. Schema of surgical approach and cerebral protection

Table 2. Surgical parameters and outcomes

Surgical duration (min)	711.9 ± 211.3
Total CPB (min)	251.8 ± 87.8
Cardiac arrest (min)	167.7 ± 75.9
SCP (min)	126.5 ± 30.5
HCA of 9 patients (min)	56.1 ± 24.6
Hospital deaths	1 (5.9%)
Mechanical ventilation duration (d)	4.6 ± 3.1
Complications	
Respiratory failure	8 (47.1%)
Cerebral infarction	0
Acute renal failure	2 (11.8%)
Hospitalization after surgery (d)	35.3 ± 6.7
Follow-up duration (m)	20.3 ± 21.3

CPB, cardio-pulmonary bypass; SCP, selective cerebral perfusion; HCA, hypothermic circulatory arrest.

distal arch aorta. Meanwhile, the left phrenic and left recurrent laryngeal nerves were identified, mobilized with the aneurysmal wall, and protected. Antegrade SCP was terminated after reconstructing the arch vessels, and the proximal side of the arch graft was then sutured to the stump of the ascending aorta. The root of the left subclavian artery was ligated and reconstructed by graft-graft anastomosis using a 5-0 polypropylene running suture.

Results

Table 2 shows that the surgical duration, total cardiopulmonary bypass time, cardiac ischemic time, and selective cerebral perfusion time were 711.9 ± 211.3, 251.8 ± 87.8, 167.7 ± 75.9, and 126.5 ± 30.5 minutes, respectively. We applied HCA to 9 patients for 56.1 ± 24.6 (range 24.5 to 85) minutes. Rectal temperatures in these patients were maintained at 20°C during HCA.

One patient who died in the hospital (hospital mortality, 5.9%) of multiple organ failure on postoperative day 17 had a distal pseudoaneurysm after arch replacement for type A dissection and required simultaneous AVR and MVR with CABG. However, this patient was not complicated with cerebral damage.

Early morbidity in 8 patients comprised pulmonary failure, defined as requiring respiratory support for >72 hours. Two patients required transient continuous hemodialysis for acute renal failure. Mechanical ventilation was required after surgery for 4.6 ± 3.1 days. Two patients with preoperative left recurrent laryngeal nerve palsy developed persistent hoarseness after the operation. No new phrenic or left recurrent laryngeal nerve palsies

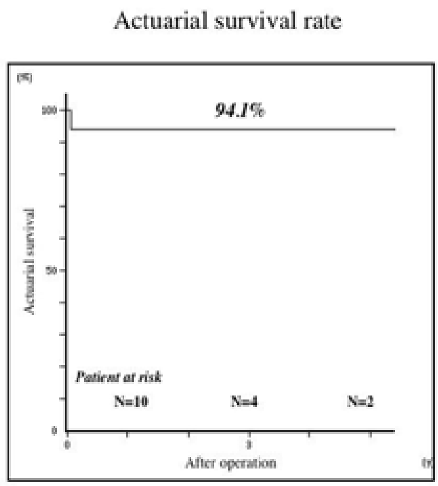

Fig. 2. Actuarial survival rates among 17 patients with extensive replacement of the thoracic aorta using biaxillary arterial perfusion.

developed as a result of surgery. Permanent neurological dysfunction and postoperative stroke did not occur in this series, and the patients remained hospitalized after surgery for 35.3 ± 6.7 days. The actuarial survival rate 5 years later was 94.1% (Fig. 2), and the patients were followed up after surgery for 20.3 ± 21.3 months.

Discussion

The prevention of cerebral embolism is an important consideration during repair of an aortic arch or ascending aortic aneurysm; thus it is a major goal of cerebral protection strategies. Selection of the optimal arterial cannulation site for CPB is critical to achieve this, and the usual site is the ascending aorta or FA.[1,2] However, a cerebral embolism can occur at both cannulation sites because of severe atherosclerotic changes in the ascending aorta near the arch aneurysm or retrograde perfusion via the femoral artery.[4,5] The important variables considered to influence the occurrence of postoperative stroke following aortic arch repair, and which might be affected by the method of cannulation, include the presence of clots and atheromas in the aorta and dissection as the etiology of aneurysms. In 1995 Svenson et al.[6] started applying a subclavian or axillary artery cannulation strategy with HCA and antegrade brain perfusion, and they found that it was a safe approach to aortic arch surgery because the stroke risk was <2%. The theoretical advantages of using the subclavian or axillary artery site for inflow during complex cardiac and cardioaortic procedures have recently become apparent.[6,7] They include a decreased likelihood of stroke from embolic material, less likely malperfusion with aortic dissection, reduced disruption of atheroma or calcified plaques, and the ability to administer antegrade brain perfusion.

Ergin et al.[8] reported that temporary neurological dysfunction is a clinical marker of an insidious but significant neurological injury associated with measurable long-term deficits in cerebral function. Therefore we have applied only SCP during aortic arch repair because of the extended duration of cerebral safety and the low incidence of temporary neurological dysfunction. In this series, cerebral perfusion was established at a flow rate of 10–15 ml/kg/min, using a double-roller pump separate from the systemic circulation. Bilateral radial artery and left carotid artery stump pressures were monitored and controlled from 40 to 50 mmHg by regulating SCP flow. Values obtained by transcranial Doppler sonography and Somanetics Invos® cerebral oximetry did not decrease in any of the patients in this series. The Cerebral Somatic Oximeter has been described as a functional and possibly a superior device for monitoring the adequacy of cerebral perfusion and oxygenation.[9,10] Therefore we supposed that our method of cerebral protection is acceptable.

However, atheromatous emboli migrating to the brain, considered the main cause of permanent neurological dysfunction, remain a major concern during SCP. Antegrade SCP is physiological, and the time taken to ensure cerebral safety should be much longer. However, arch-vessel cannulation is required for this maneuver, which carries a risk of cerebral embolization. Many embolisms arise as a result of systemic CPB perfusion via the ascending aorta across the arch aneurysm; otherwise, it is because of retrograde CPB perfusion via the FA or cannulation to the arch vessels for SCP. The need to cannulate arterial vessels and to manipulate often severely atherosclerotic aneurysms enhances the potential for embolization into the cerebral circulation, resulting in focal lesions and neurological injury. Svenson and colleagues[7] described that when the subclavian or axillary arteries were used for inflow, direct cannulation is associated with a greater risk of local complications, including dissection of the artery, inadequate flow, abutment of the cannula tip against the carotid artery wall, and tears that are difficult to repair because arterial tissue is fragile and often traumatized. We switched arterial inflow to a side graft sewn onto the vessels, which avoided having to perform delicate and complex repairs of artery at the end of the procedure. Instead, the side graft could simply be oversewn and tied off or clipped. We doubt whether whole brain perfusion is sufficient with only right axillary artery perfusion. The best approach for cerebral protection during these procedures remains a matter of controversy. Although the procedures are continually undergoing refinement with improved results, associated brain injury can still arise despite the application of all cerebral protection techniques suitable for these operations. Thus we added left-side brain perfusion. Moreover, vertebral perfusion via the left axillary artery is important for spinal and cerebral protection. Simultaneously sewing a graft to a bilateral axillary artery takes about 20 to 30 minutes. The axillary artery always has less atherosclerotic change than the ascending aorta or the FA, and it can easily be exposed.[12] During reconstruction of the left subclavian artery, a side graft could simply be sewn onto another graft that had been anastomosed to the left axillary artery beforehand.

Indications for approaches in patients with arch aneurysms are controversial because the surgical results of extended arch replacement are suboptimal. The combined surgical approach (median sternotomy with left anterolateral thoracotomy) to treating thoracic aortic aneurysms has been considered too invasive. However, we have lately experienced 25 consecutive patients with extended thoracic aortic aneurysms who underwent total replacement of the arch and descending aorta through this combined approach without postoperative severe respiratory dysfunction. Especially in the distal reoperative situation for dissecting type A, the retrosternal space can be easily excised from a left thoracotomy, though adhesion resulting from previous surgeries can be moderate or severe. However, almost all patients in this series required effective sputum suction using Bronco fiber after operation in the intensive care unit. Moreover, we have recently used a free arm holder with retractor to lift up the lung to prevent injury caused by compression during operations. Thereafter, respiratory dysfunction as a result of bloody sputum discharge was significantly decreased. We presume that patients who have insufficient respiratory function, especially chronic obstructive pulmonary disease (COPD), should be excluded from this approach to avoid postoperative pulmonary disorders. In the same period, 2 cases with COPD and 1 with left lung carcinoma were excluded from this approach to prevent pulmonary complications. Further, a usual Stanford type A dissection that required ascending, even though an arch replacement does not indicate bilateral axillary perfusion or the open-door approach because they would complete the procedure only through a median approach. In such cases, we perfuse via the right axillary artery with the right femoral artery by direct cannulation. Moreover, if dissection developed to subclavian arteries, anastomosing the graft to the axillary artery might be difficult. Fortunately we have not experienced a situation of this kind.

We believe that extensive reimplantation of the thoracic aorta, accompanied by adequate distal aortic perfusion under distal clamping to avoid HCA, is effective. It is important to distal perfusion for preservation of the spine, and also for visceral organ protection. Furthermore, there were no time limitations for certain organ preservation when distal perfusion was established.

Neither permanent neurological dysfunction nor postoperative stroke developed in this series. We consider that perfusion from the bilateral axillary arteries for total arch replacement can help to prevent cerebral damage. This study is limited by its relatively small size. However, the analysis of our results may have practical implications for the ongoing evolution in severe cases of this kind.

References

1. Crawford ES, Kirklin JW, Naftel DC, Svensson LG, Coselli JS, et al. Surgery for acute dissection of ascending aorta: should the arch be included? *J Thorac Cardiovasc Surg* 1992; **104**: 46–59.
2. Kazui T, Washiyama N, Bashar AHM, Terada H, Suzuki T, et al. Surgical outcome of acute type A aortic dissection: analysis of risk factors. *Ann Thorac Surg* 2002; **74**: 75–82.
3. Okita Y, Ando M, Minatoya K, Kitamura S, Takamoto S, et al. Predictive factors for mortality and cerebral complications in atherosclerotic aneurysm of the aortic arch. *Ann Thorac Surg* 1999; **67**: 72–8.
4. Westby S, Katsumata T. Proximal aortic perfusion for complex arch and descending aortic disease. *J Thorac Cardiovasc Surg* 1998; **115**: 162–7.
5. Numata S, Ogino H, Sasaki H, Hanafusa Y, Hirata M, et al. Total arch replacement using antegrade selective cerebral perfusion with right axillary artery perfusion. *Eur J Cardiothorac Surg* 2003; **23**: 771–5.
6. Svenson LG, Nadolny EM, Penney DL, Jacobson J, Kimmel WA, et al. Prospective randomized neurocognitive and S-100 study of hypothermic circulatory arrest, retrograde brain perfusion, and antegrade brain perfusion for aortic arch operations. *Ann Thorac Surg* 2001; **71**: 1905–12.
7. Svenson LG, Blackstone EH, Rajeswaran J, Sabik JF, Lytle BW, et al. Does the arterial cannulation site for circulatory arrest influence stroke risk? *Ann Thorac Surg* 2004; **78**: 1274–84.
8. Ergin MA, Uysal S, Reich DL, Apaydin A, Lansman SL, et al. Temporary neurological dysfunction after deep hypothermic circulatory arrest: a clinical marker of long-term functional deficit. *Ann Thorac Surg* 1999; **67**: 1887–90.
9. Fassiadis N, Zayed H, Rashid H, Green DW. Invos® Cerebral Oximeter compared with the transcranial Doppler for monitoring adequacy of cerebral perfusion in patients undergoing carotid endarterectomy. *Int Angiol* 2006; **25**: 401–6.
10. Samra SK, Dy EA, Welch K, Dorje P, Zelenock GB, Evaluation of a Cerebral Oximeter as a monitor of cerebral ischemia during carotid endarterectomy. *Anesthesiology* 2000; **93**: 964–70.