

Cardiopulmonary Bypass for Thoracic Aortic Aneurysm: A Report on 488 Cases

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Abstract: Our objective was to investigate different cardiopulmonary bypass (CPB) techniques for thoracic aortic aneurysm retrospectively. Four hundred and eighty-eight patients with thoracic aortic aneurysm received surgical treatment. Total CPB was used routinely in 331 cases with ascending aortic aneurysm. When the aneurysm expanded to the aortic arch, brain protection was executed by adopting deep hypothermia circulatory arrest (DHCA) or DHCA combined with retrograde cerebral perfusion (RCP). Selected cerebral perfusion via carotid artery was used in three cases and separated upper and lower body perfusion in five cases. Left heart bypass was adopted for the surgeries of 157 cases with descending aortic aneurysm. In two of the cases, ventricular defibrillation could not be achieved, and then bypass was altered to separated upper and lower body perfusion to acquire satisfactory outcome. In the ascending aortic aneurysm group, DHCA time in the 17 patients was 10–63 minutes (mean 35.58 ± 18.81 min), and DHCA \pm RCP time in 61 patients

was 16–81 minutes (mean 43.43 ± 17.91 min). Total mortality of aortic aneurysm surgery requiring full CPB was 5.4% (18/331), in which eight patients died in emergency operations. The total mortality of emergency operation was 11.9% (8/67). In the descending aortic aneurysm group, time of left heart bypass was 125.56 ± 57.28 min, and the total mortality was 7% (11 of 157 patients). Three patients developed postoperative paraplegia. Techniques for extracorporeal circulation for surgery of the aorta are dependent on the nature of the disease and require a flexible approach to meet the specific anatomical challenge. The ability to alter the perfusion circuit to meet unexpected situations should be anticipated and planned for. In this series, we have varied our approach to perfusion techniques as required with acceptable outcome data as compared to the international literature. **Keywords:** thoracic aortic aneurysm, retrograde cerebral perfusion, hypothermic circulatory arrest, brain protection, cardiopulmonary bypass. *JECT. 2004;36:22–27*

Thoracic aortic aneurysm, especially dissecting aortic aneurysm, is a catastrophic and life-threatening disease. With advancement in diagnostic techniques and understanding of the disease over the past two decades, surgical cases of thoracic aortic aneurysm have increased. Once patients are diagnosed and scheduled for surgery, cardiopulmonary bypass (CPB) is usually required. Differing bypass techniques were adopted according to the type, location, and extent of the lesions. Some unexpected situations may occur during CPB, and immediately an alternative bypass technique is needed to protect vital organs. Central nervous system dysfunction is one of the most serious complications after thoracic aortic surgery (1). Intraoperative brain protection is the key factor that influences the outcome of surgery (2,3). This retrospective study reports and analyzes the bypass technique of thoracic aortic aneurysm in our institute.

MATERIALS AND METHODS

Patient Data

From May 1982 to April 2001, 488 patients with thoracic aortic aneurysm received surgical treatment. Three hundred and thirty-three patients were diagnosed with ascending aortic aneurysm consistent with Marfan syndrome, and DeBakey type a and type b aneurysms. One hundred and fifty-seven patients who were diagnosed with descending aneurysm consisted of aneurysm, false aneurysm, DeBakey type a, and type b dissecting aneurysm.

Anesthesia Procedure

Standard anesthesia management was used for all patients. For premedication, 0.01 mg/kg scopolamine and 0.2 mg/kg morphine were given intramuscularly 2 hours before surgery. Anesthesia induction was accomplished with midazolam 0.15–0.3 mg/kg, pancuronium bromide 0.1–0.2 mg/kg, droperidol 0.1–0.2 mg/kg, and fentanyl 10–40 μ g/kg. Anesthesia was maintained by fentanyl and isoflurane intermittently.

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Cardiopulmonary Bypass for Ascending Aortic Aneurysm

Operations were performed through a median sternotomy and routine total cardiopulmonary bypass was used in this group. Cardiopulmonary bypass was performed with a nonpulsatile roller pump (Stockert Shiley II, Stockert, Munich, Germany), membrane oxygenator (Bentley, Baxter, Irvine, CA), and 40 μm arterial line filter (AF-1040 Gold, Bentley, Baxter, Irvine, CA). A balanced prime (1000 mL of Ringer's lactate solution, 1000 mL of modified gelatin substitute, 125 IU/kg heparin) was used. After systemic heparinization (400 IU/kg, ACT > 480 sec), CPB with moderate systemic hypothermia (28°C–30°C nasopharyngeal temperature) was initiated. Venous blood was drained through either two-stage cannula or bicaval cannulas, and oxygenated blood was perfused through a cannula inserted into aortic or femoral artery. Initial CPB was established at flow rate of 2.2–2.4 L/min/m². The patients were cooled gradually. During the cooling phase, ice packs were placed around the patients' heads to enhance cerebral hypothermia. The discrepancy between water temperature and blood temperature was below 10°C. The rate of cooling and rewarming was about 0.33°C/min. After the heart was fibrillated, myocardial protection was effected by with crystalloid cardioplegia in the first 47 cases and 4:1 blood cardioplegia in the following patients.

In this group, there were 252 patients with ascending aortic dissecting aneurysm. Eighty-one patients' dissecting aneurysms involved aortic arch or right half of the arch. To protect the brain, different methods were adopted in four subgroups.

Seventeen patients were assigned to Group I, in which deep hypothermic circulatory arrest (DHCA) was used. After nasopharyngeal temperature reached 18°C, and rectal temperature 20°C, CPB was discontinued. The arch vessels were repaired or replaced.

Fifty-six patients were assigned to Group II, in which retrograde cerebral perfusion (RCP) was performed. After cooling to the same temperature as those in Group I, patients were put in the Trendelenburg position, and RCP was started via the superior vena cava. RCP flow rate was 100–600 mL/min and was adjusted by maintaining the central venous pressure (CVP) around 25 mmHg. The temperature of inflow blood during RCP was 17–18°C. The aortic clamp was released, and the open anastomosis was easily made (Figure 1).

Three patients were assigned to Group III, in which selected cerebral perfusion via carotid artery was carried out. These three patients with Debakey I dissecting aneurysm were perfused through a femoral arterial cannula. Soon after the heart arrest, a sudden reduction of the radial artery blood pressure reflected an absence of cerebral blood flow by femoral artery retrograde perfusion. The time of brain ischemia was 70 minutes in the first case

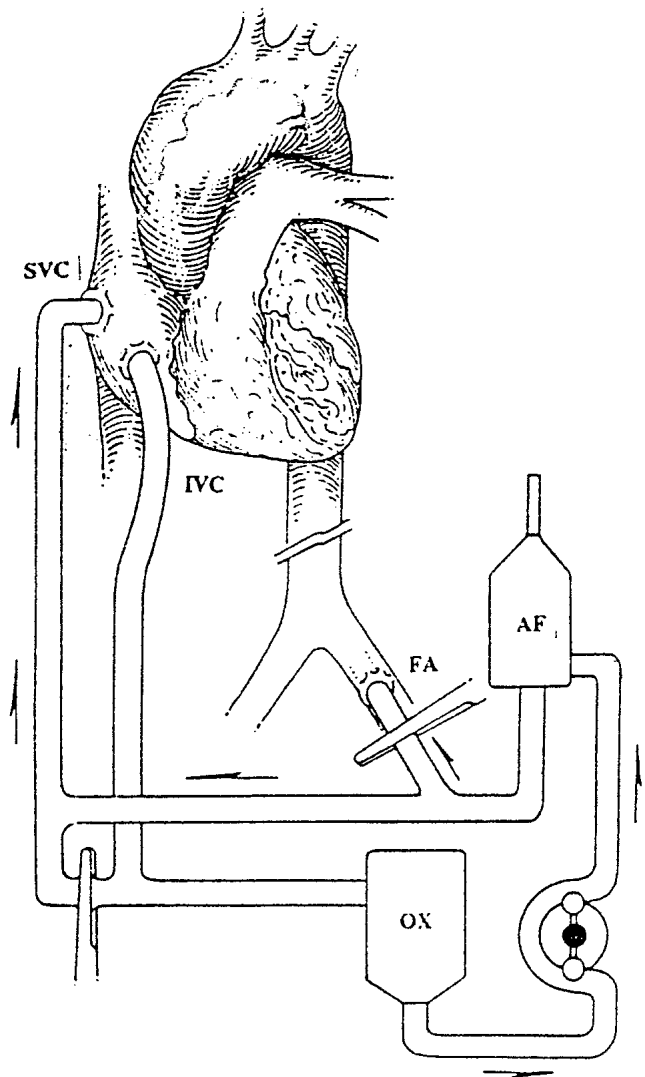


Figure 1. Retrograde cerebral perfusion. OX: oxygenator; AF: arterial filter; FA: femoral artery; SVC: superior vena cava; IVC: inferior vena cava.

because of not having encountering this kind of urgent situation and ignoring potential cerebral injury. From the experience of the first case, it took only 20 and 24 minutes in the latter two cases until an additional cannula was inserted into left carotid artery for brain perfusion (Figure 2). The temperature of inflow blood in the latter two patients was between 17 and 27°C.

In Group IV, separated upper and lower body perfusion was performed. In this group, there were five patients with rupture of aneurysm to the descending aorta and dissected intima extending retrograde to the arch and ascending aorta. A median sternotomy incision plus a left lateral incision was used, and separate upper and lower body perfusion through the ascending aortic and femoral artery was established. In three patients of this group, RCP was used for cerebral protection during deep hypothermia

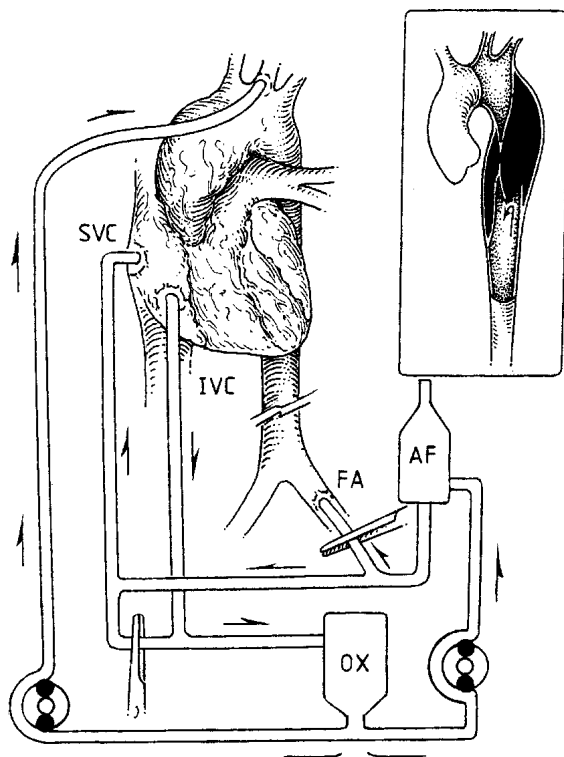


Figure 2. Reestablishing cerebral perfusion. OX: oxygenator; AF: arterial filter; FA: femoral artery; SVC: superior vena cava; IVC: inferior vena cava.

while lower body perfusion continued (Figure 3). There were 61 patients with RCP for cerebral protection in Groups II, III, and IV.

Left Heart Bypass for Descending Aortic Aneurysm

In this group, a postlateral incision was made. Left heart bypass was carried out by partial draining of blood from either the left atrium via the appendage or the left superior pulmonary vein or proximal aorta. Arterial return is provided through the femoral artery or distal descending aorta. In the whole group, bypass was modified by using an oxygenator as a reservoir, which could also provide temperature control via a heat exchanger during prolonged bypass. Ventricular fibrillation occurred in five patients, four of whom were defibrillated successfully. The patient who could not be defibrillated was converted to total CPB by aorta arch cannulation and venous return via the pulmonary outflow tract. Sinus bradycardia and cardiac arrest occurred in one other patient after proximal clamping and total CPB, as the patient was adapted.

Intraoperative mortality was defined as death on the day of operation or during the procedure and postoperative mortality as death within 72 hours postoperation. Adverse outcome was defined as permanent injury at the time of discharge from the hospital, whether focal (embolic stroke) or global (diffuse coma). Transient neuro-

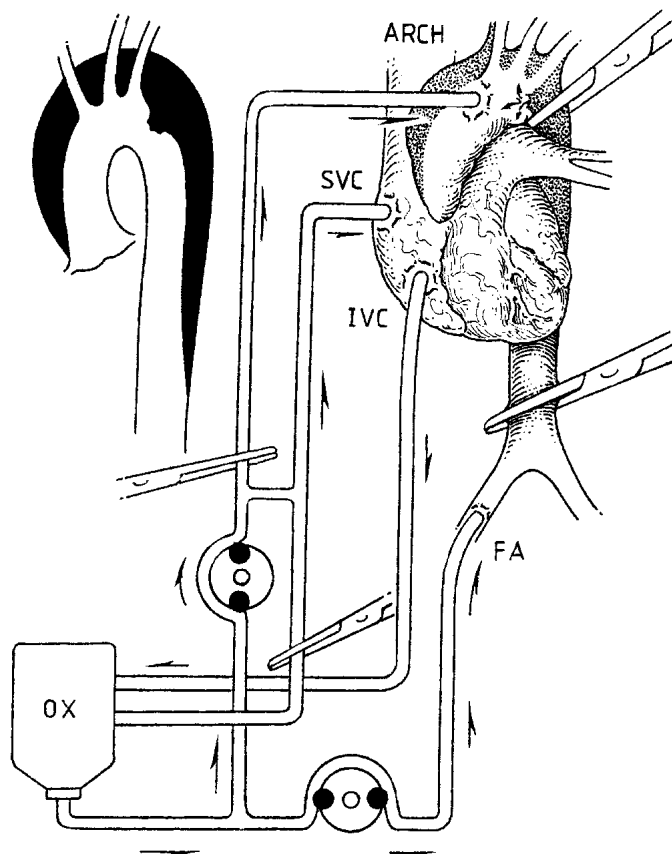


Figure 3. Separated upper and lower body perfusion. OX: oxygenator; AF: arterial filter; FA: femoral artery; SVC: superior vena cava; IVC: inferior vena cava; ARCH: aortic arch.

logic dysfunction was defined as the occurrence of prolonged postoperative confusion, agitation, or transient delirium or ischemic deficits.

Statistical Analysis

The data were expressed as mean \pm standard deviation ($X \pm SD$). Comparison between two groups was done using the *t*-test and chi-square test. A *p*-value less than .05 was considered significant.

RESULTS

The clinical data are listed in Table 1. Most patients with ascending aortic aneurysm underwent Bentall procedures (192 cases). Total aortic arch replacement was performed in 13 cases and partial arch replacement in four cases (Table 2).

The duration of DHCA in Group I was 35.58 ± 18.81 min (range, 10–63 min), and duration of DHCA + RCP time in Groups II–IV was 43.43 ± 17.91 min (range, 16 to 81 min).

Outcome data are summarized in Table 3. There were three intraoperative deaths in the DHCA group and one in the RCP group. There were two patients in the DHCA group and one patient in the RCP group with permanent

Table 1. Clinical data of patients with thoracic aortic aneurysm.

	Age (y)	CPB Time (min)	Aortic Cross Clamp Time (min)	Time of Intubation (h)
Ascending aortic aneurysm (<i>n</i> = 331)	43.50 ± 2.90	178.11 ± 57.36	125.80 ± 41.84	30.10 ± 25.42
Descending aortic aneurysm (<i>n</i> = 157)	48.05 ± 0.27	114.73 ± 60.18		34.49 ± 76.64

Table 2. Surgical data of patients with thoracic aortic aneurysm.

	Cases	Surgical Type	
		Surgical Technique	Cases
Ascending aortic aneurysm	331	Bentall	192
		Wheat	64
		Cabrol	3
		Robicsek	3
		Ascending aorta replacement	39
		Total arch replacement	13
		Partial arch replacement	4
Descending aortic aneurysm	157	Ascending aorta repaired	13
		Descending aortic replacement (two of them plus intercostal artery reimplantation)	43
		Descending aortic repaired	114

neurological complications who died postoperatively. There were three patients in the DHCA group and two patients in the RCP group with temporary neurological deficiency, including prolonged postoperative confusion, agitation, or transient delirium. All these patients with temporary neurological deficiency recovered after 72 hours without obvious mental and physical abnormal symptoms. Comparison analysis showed there was significant lower postoperative mortality related to neurological injury in the RCP group (1.7%, 1/60) than that in the DHCA group (14.3%, 2/14) ($\chi^2 = 4.647, p = .031$). Significant more neurological complications occurred in the DHCA group (25%, 3/12) than those in the RCP group (3.4%, 2/59) ($\chi^2 = 7.114, p = .008$).

Intraoperative mortality in the patient with ascending aortic aneurysm was 3.02% (10/331). Eight patients died of massive bleeding, and two of refractory arrhythmia. Postoperative mortality was 2.49% (8/321), and total mortality was 5.43% (18/331) (Table 3).

Table 3. Outcome of patients with thoracic aneurysm after operation.

	Intraoperative Mortality		Postoperative Mortality		Complications
	Cases	Cause	Cases	Cause	
Ascending aortic aneurysm	10	Massive bleeding (8 cases) Refractory arrhythmia (2 cases)	8	Serious neurological injury (3 cases) Renal failure (4 cases) Respiratory failure (1 case)	Temporary neurological deficiency (3 cases in DHCA group and 2 cases in RCP group) Paraplegia (3 cases)
Descending aortic aneurysm	3	Uncontrollable bleeding (2 cases) Refractory arrhythmia (1 case)	8	Stroke (1 case) Respiratory failure (1 case) Renal failure (3 cases) Stress ulcer syndrome (1 case) Refractory arrhythmia (2 cases)	

Sixty-seven emergency operations were performed in the ascending aortic aneurysm group. The mortality of emergency operation was 11.9% (8/67).

In the descending aortic aneurysm group, descending aorta was replaced by prosthesis in 43 patients. Intercostal artery reimplantation was performed in two patients. The remaining patients had partial resection of the thoracic aneurysm with patch repair.

Intraoperative mortality was 1.91% (3/157), with massive bleeding and refractory arrhythmia the major contributing reasons. Postoperative mortality was 5.19% (8/154), and total mortality was 7% (11/157). Three patients developed paraplegia postoperatively (1.91%, 3/157) (Table 3).

DISCUSSION

Surgery of a thoracic aneurysm is always considered a complicated and time-consuming procedure. Surgical mortality is caused not only by the complexity of the operative procedure but also by the adverse effect of the extracorporeal circulation. Despite a low incidence of major neurological injury following routine cardiac surgery, it is still a significant cause of postoperative mortality and morbidity in thoracic aortic surgery (4). Differing bypass techniques should be considered according to the pathological location of thoracic aortic aneurysm, the surgical procedure, vital organ protection, and unique situations.

In our institute, 331 surgeries for ascending aortic aneurysm were performed with CPB. Arterial perfusion was provided through a cannula placed either in the distal descending aorta or femoral artery, and total CPB was used. 81 patients with dissecting aneurysm involving the aortic

arch. They were allocated to different methods of brain protection: DHCA (17 patients) and RCP (61 patients).

It is well known that the duration of DHCA should be limited to 60 min (1,5,6). In this retrospective study, the duration of DHCA ranged from 10 to 63 min, with a mean of 35 min. The longest time of RCP was 81 min, with a mean of 43 min. Analysis indicated a higher operative mortality because of neurological injury and more neurological complications in the DHCA Group as compared to the RCP Group ($p = .008$). Therefore, RCP could prolong the safe duration of circulation arrest. In addition, open anastomosis of aorta to prosthesis without clamping the arch vessels can be safely performed to reduce neurological complications. It has been demonstrated that clamping the aortic arch for anastomosis is the greatest risk factor for stroke (4).

In patients with DeBakey I dissecting aneurysm, cannulation of femoral artery and establishment of retrograde flow followed by placement of an occlusive clamp on the ascending aorta may result in compression of the true lumen by the intimal flap. Because the proximal communication between the true and false lumens is excluded, it may severely impair perfusion of brain and other organs during the time the aorta is clamped (Figure 3) (7,8). The perfusionist must anticipate this situation and be prepared to use alternate bypass options. In Group III, after aorta cross clamping, immediate reduction of the radial artery pressure indicated impaired perfusion of the brain. Preoperative MRI of these three patients showed distal re-entry presence. The intimal flap in these patients prevented adequate blood flow by femoral artery retrograde perfusion. The surgeon reinserted a cannula into the carotid artery to provide antegrade brain perfusion. The first case died of cerebral injury caused by the delayed restoration of brain perfusion up to 70 minutes. The other two patients recovered completely without any neurological complication.

In Group IV, the extent of the dissection provided a challenging situation. Separated upper and lower body perfusion was beneficial to protect the whole body from ischemia. During reconstruction of the aortic arch, RCP was used for brain protection while the lower body was perfused with continuous adequate blood flow in three patients.

Some reports have showed that emergency is high risk factor for post-operative mortality and complications of surgery for thoracic aortic aneurysm (9,10). In this study, the mortality of emergency (11.9%) was higher than elective operations (3.79%, 10/264) ($\chi^2 = 6.907$, $p = .009$).

In this series of descending aortic aneurysms, we used left heart bypass on the basis that this technique would have a lesser impact on the whole body compared to total CPB and would be sufficient to protect the visceral organs, spinal cord, and lower extremities (11–13). Ischemic injury to the spinal cord and/or visceral organs is a disastrous

complication of dissected thoracic or thoracoabdominal aortic repairs (14–19). The risk of spinal cord damage is higher for repair of acute dissection than for arteriosclerotic aneurysms because chronically occluded intercostal arteries in aneurysm patients may stimulate development of spinal cord collaterals that partially protect against ischemic injury. The result showed post-operative paraplegia occurred in three patients without reimplantation of intercostal artery. Two patients with intercostal artery reimplantation underwent uneventful recovery process. Where a long segment of the descending aorta requires resection, reimplantation of major intercostal arteries arising from the resected section of the aorta should be seriously considered to reduce occurrence of paraplegia (20–24).

Unexpected ventricular fibrillation or cardiac arrest may occur during left heart bypass procedures. Four patients were defibrillated successfully and left heart bypass continued. Two patients who could not be defibrillated immediately were converted to total CPB. Separated upper and lower body perfusion was used for whole body protection.

We had modified the circuit of the left heart bypass by using an oxygenator as a reservoir. As a result, volume could be easily managed where massive bleeding occurred, temperature control was facilitated by using the integral heat exchanger, and conversion to full bypass was possible where required (25,26).

CONCLUSION

Techniques for extracorporeal circulation for surgery of the aorta are dependent on the nature of the disease and require a flexible approach to meet the specific anatomical challenge. The ability to alter the perfusion circuit to meet unexpected situations, such as conversion from LA–FA to full CPB intraoperatively or the application of selective antegrade cerebral perfusion, should be anticipated and planned for. In this series, we have varied our approach to perfusion techniques as required with acceptable outcome data compared to the international literature.

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