PROXIMAL AORTIC PERFUSION FOR COMPLEX ARCH AND DESCENDING AORTIC DISEASE

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Objective: Cannulation of the femoral artery is used routinely for hypothermic circulatory arrest operations on the aortic arch. A two-stage approach is advocated for combined arch and descending aortic disease. These methods are associated with important neurologic injury through embolism or malperfusion. We therefore changed to a central cannulation technique through extended left thoracotomy. **Methods:** Eighteen patients with arch or combined pathologic conditions underwent one-stage repair with hypothermic circulatory arrest using ascending aortic cannulation and venous drainage from the pulmonary artery. Emergency operations were performed for bleeding or dissection. Cerebral and myocardial perfusion were restored during descending aortic replacement. **Results:** One elderly patient died of gastrointestinal hemorrhage after initial recovery (overall mortality 5.6%, range 0.14% to 27%, $p = 0.05$). One possible transient monoparesis occurred but without computed tomographic scan evidence of embolism. No other significant events and no morbidity occurred from the surgical methods. **Conclusions:** Extended left thoracotomy with central cannulation allows safe one-stage replacement of the arch and descending aorta using antegrade cerebral perfusion. We believe that this method will reduce cerebral complications in arch and descending aortic operations. (J Thorac Cardiovasc Surg 1998;115:162-7)

Cannulation of the femoral artery with retrograde aortic perfusion and profoundly hypothermic circulatory arrest is the standard approach for surgery of the aortic arch.¹ A two-stage technique using the elephant trunk method is advocated when disease extends into the descending thoracic aorta.² We believe that there are disadvantages in this approach. First, the whole thoracic aorta can be replaced without difficulty in a single operation. Second, perfusion of the brain retrogradely through an atheromatous or chronically dissected thoracoabdominal aorta conveys the risk of widespread cerebral embolism or maldistribution of flow. In our practice between 5% and 10% of arch aneurysm or chronic dissection patients have cerebral injury because of this problem (Fig. 1). Consequently, we

have changed our strategy for arch and descending aortic conditions to provide antegrade cerebral perfusion through the shortest possible length of diseased aorta. Whenever possible, we perform a one-stage replacement of the aortic arch and descending thoracic aorta for atherosclerotic aneurysms or chronic type B dissection. This article describes the operative approach in 18 consecutive patients in whom extended left thoracotomy, central cannulation, and antegrade arterial flow were used.

Patients and methods

From June 1991 to December 1996 18 patients underwent repair of aortic arch and descending thoracic aortic conditions with the central cannulation method through extended left thoracotomy. The patient details are summarized in Table I. Ten male and eight female patients, whose ages ranged from 33 to 76 years (mean 62 years), were included in this study. One patient had Marfan's syndrome (Fig. 2, A) and 15 (83%) were treated for hypertension. Nine patients had atherosclerotic aneurysms. Seven were fusiform, involving part or the whole of the aortic arch and extending into the descending thoracic aorta in five. Two atherosclerotic aneurysms were saccular, with an entry point opposite the left common carotid artery. Another patient had a saccular aneurysm beneath the arch, originating from an aortic homograft replace-

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ment of congenital coarctation of the aorta 40 years earlier (Fig. 2, B). The youngest patient had a congenital aortic arch coarctation just proximal to the left subclavian artery. The remaining seven patients had acute ($n = 1$) or chronic ($n = 6$) aortic dissection involving the arch and descending thoracic aorta. At operation one of these patients was found to have type B dissection in a poststenotic dilatation distal to an unexpected midarch coarctation. Emergency operation was required for leaking aneurysm in three (17%) patients, two with dissection and one with a ruptured atherosclerotic arch aneurysm. All 18 patients were investigated by computed tomographic scanning. Seven patients had nuclear magnetic resonance imaging and nine patients had aortography before surgery. Two patients with type A dissection involving the entire aortic arch had transesophageal echocardiography for the proximal extension of the false lumen. This information helped to determine the site of aortic cannulation. If a past history of angina or myocardial infarction was present in elective cases, coronary angiography was also performed. All patients were given a general physical examination for their neurologic status before and after operation (within 3 days of extubation).

Operative technique. A double-lumen endotracheal tube was used to allow collapse of the left lung. A combination of neuroprotective agents of nimodipine (1 mg/hr), thiopental (6 mg/kg loading dose, then 6 mg/kg per hour), and mannitol (5 mg/kg) was administered in the anesthetic room. The patient was placed on the operating table in the left lateral position. While the pelvis was at 90 degrees to the operating table, the shoulders were rotated about 30 degrees from vertical toward the surgeon, thereby improving access to the sternum. The whole chest and abdomen were prepared and draped to allow extension of the thoracotomy transversely across the sternum. Thoracotomy was then performed through the fourth intercostal space and the sternum transected. When concomitant coronary bypass was required, the left internal thoracic artery was harvested; if not, the vessel was divided. When the aortic pathologic condition extended to the diaphragm, the fifth rib was routinely excised to increase exposure. The extended left thoracotomy provided access to the whole thoracic aorta and to the left coronary artery system. (For thoracoabdominal replacement a second incision is used through the seventh intercostal space).

Arterial return was first established with a short, angled cannula in the ascending aorta (Fig. 3). The site was chosen to avoid potential embolic material, where the manual palpation of the ascending aorta was routinely given for calcification. Venous return to the pump oxygenator was through a right-angled venous cannula in the main pulmonary artery and passed through the pulmonary valve into the right ventricle. These cannulas were secured anteriorly in the wound, away from the main operative field. Cardiopulmonary bypass was then established with cooling of the nasopharyngeal temperature to 20° C. Meanwhile the left phrenic nerve and left recurrent laryngeal nerve were identified, mobilized from the aneurysm, and protected. When coronary grafts were required, the distal anastomoses were performed during the cooling period. At 20° C the patient was tilted, head down, and the

Fig. 1. Computed tomographic scan 2 days after complete thoracic aortic replacement of an atheromatous aneurysm, using retrograde aortic perfusion through the femoral artery. The abnormalities are embolic cerebral infarcts in the territories of the right anterior and middle and left cerebral arteries. Because the descending thoracic aorta was not manipulated before circulatory arrest, the emboli must have originated through perfusion of the diseased thoracoabdominal aorta.

circulation arrested. Venous blood was drained into the oxygenator. For patients having coronary bypass, the ascending aorta was temporarily crossclamped and cold crystalloid cardioplegic solution (St. Thomas' Hospital solution) infused. Cardioplegia was not used for aortic resection alone when relatively short periods of total circulatory arrest (less than 30 minutes) were required. The aortic arch was then opened and for complete arch replacement the head vessels were mobilized collectively on a single aortic patch. The aortic arch was replaced by anastomosing this patch to a collagen-impregnated vascular graft, the proximal end of which was then used to replace the appropriate length of ascending aorta. If the ascending aorta was normal, the arterial cannula was left in its original position. When the whole ascending aorta was replaced, the arterial cannula was repositioned within the vascular graft. Single tube grafts were used for the arch and the descending aorta. The new ascending aorta and arch were then deaired, and a vascular clamp was placed on the graft distal to the left subclavian artery. In

Table I. Demographic and pathologic data, surgical procedure, and outcome after thoracic aortic replacement with the proximal aortic perfusion method

Patient	Age	Sex	Extent of lesion	Type	Procedure	Complication	Outcome
1	76	F	Complete arch	Fusiform	TAR	GI bleeding	Died on 5 POD
2	33	M	Midarch	Co/A	Coarctectomy	None	Alive
3	67	M	Complete arch—DA	Fusiform	TAR	None	Alive
4	71	F	Distal arch—DA	Fusiform	TAR	None	Alive
5	67	M	Distal arch	Saccular	Patch	None	Alive
6	39	M	Complete arch—DA	Chronic type A	TAR	None	Alive
7	69	F	Distal arch—DA	Fusiform	TAR	Monoparesis	Alive
8	75	M	Distal arch	Saccular	Patch + CABG	None	Alive
9	53	F	Distal arch—DA	Fusiform	PAR + DAR	None	Alive
10	76	F	Distal arch—DA	Chronic type A	PAR + DAR	None	Alive
11	74	M	Distal arch—DA	Acute type B	PAR	None	Alive
12	60	M	Distal arch	Saccular post Co/A repair	PAR	None	Alive
13	70	F	DA	Chronic type B	PAR + DAR	None	Alive
14	63	M	Complete arch—DA	Chronic type A	TAR + DAR	None	Alive
15	54	F	DA	Chronic type B on Co/A	PAR + DAR	None	Alive
16	39	F	Distal arch—DA	Chronic type B	PAR + DAR	None	Alive
17	62	M	Distal arch—DA	Fusiform	PAR + DAR	High creatinine	Alive
18	63	F	Distal arch—DA	Fusiform	PAR + DAR	None	Alive

CABG, Coronary artery bypass grafting; Co/A, coarctation of the aorta; DA, descending thoracic aorta; DAR, descending thoracic aortic replacement; Fusiform, atherosclerotic fusiform aneurysm; GI, gastrointestinal; PAR, partial arch replacement; POD, postoperative day; Saccular, atherosclerotic saccular aneurysm; TAR, total arch replacement.

patients with complete arch replacements, temporary retrograde venous perfusion was used to disperse air and debris from the carotid vessels through a balloon catheter introduced into the right internal jugular vein through the innominate vein. We did not use continuous retrograde jugular venous perfusion. After a short period of total circulatory arrest for the two aortic anastomoses (Table II), cardiopulmonary bypass was reestablished to restore antegrade cerebral perfusion, together with coronary flow. The descending thoracic aorta was then replaced without time constraint, thereby allowing careful attention to intercostal reimplantation and hemostasis. Rewarming was initiated at restoration of pump flow because the low perfusion rates (1 L/min) at this time do not cause rewarming of the cold ischemic viscera. Proximal coronary anastomoses were performed during rewarming and great care taken to deair the descending aortic graft so as to avoid visceral air embolism. The extent of aortic resection or repair is shown for each patient in Table I.

All patients with atherosclerotic aneurysms underwent excision and replacement of the whole dilated aortic segment. Four had total arch replacement, and three had

distal hemiarch replacement together with descending thoracic replacement. The saccular atheromatous aneurysm, which caused compression of the pulmonary arteries, was excised with patch repair of the underside of the arch. This patient also had unstable angina and underwent left internal thoracic artery graft to the left anterior descending coronary artery with a saphenous vein graft to the circumflex branch. The patient reoperated on for a mediastinal false aneurysm, in association with the degenerate, aortic homograft, underwent resection of the distal arch, calcified homograft, and dilated proximal descending aorta. Similarly, the midarch coarctation was resected with graft replacement of the site of narrowing and poststenotic dilatation.

For patients having dissection, the entire proximal dissected segment, including the intimal tear, was resected, along with the descending thoracic aorta. Four patients had type B dissection with retrograde extension into the aortic arch. Three had chronic type A dissection with the intimal tear in the arch. Total arch replacement was required in two of these patients, whereas five patients underwent distal arch replacement. In all seven

Fig. 2. **A**, Chronic type B dissection in a patient with Marfan syndrome. **B**, Saccular aneurysm beneath the aortic arch in the patient with aortic homograft repair of aortic coarctation 40 years earlier.

patients having dissection, the whole descending thoracic aorta was replaced with beveling of the distal anastomosis to include intercostal vessels between T8 and L1. All patients underwent fenestration of the distal two-channeled aorta. In the patient with Marfan syndrome a suprarenal anastomosis was performed and the lower intercostal vessels reimplanted on a button. The 54-year-old female patient with a bicuspid aortic valve and chronic type B dissection of 15 cm diameter had previously undergone computed tomographic and magnetic resonance imaging scans that failed to demonstrate the congenital midarch coarctation. During thoracotomy the collateral arteries in the chest wall were recognized and on opening the aneurysm, which extended to midarch, only a 3 mm orifice proximal to the left subclavian artery gave access to the ascending aorta. For this patient the underside of the aortic arch was excised and replaced together with the whole descending thoracic aorta. The total operating times ranged from 130 minutes to 250 minutes (mean 198 minutes). Duration of cardiopulmonary bypass, hypothermic circulatory arrest, and spinal cord ischemic times are presented in Table II.

Statistical analysis. The incidence of adverse and other events is shown as percentage and 95% confidence limits.

Results

Outcome and morbid events are summarized in Table I. One hospital death (30-day mortality, 5.6%, range 0.14% to 27%, $p = 0.05$) occurred in the 76-year-old woman with a ruptured atherosclerotic

Fig. 3. The central cannulation technique through extended left thoracotomy.

aneurysm of the aortic arch. The fusiform aneurysm, which had previously leaked, ruptured into the left side of the chest during anesthetic induction and passage of the endotracheal tube. Both circulation

Table II. Duration of perfusion, circulatory arrest, and myocardial ischemia

	Net perfusion (min)	Cerebral circulatory arrest (min)	Distal circulatory arrest (min)	Myocardial ischemia (min)
Total (<i>n</i> = 18)	82 (58-138)	27 (14-45)	38 (21-55)	28 (14-45)
TAR (<i>n</i> = 6)	76 (64-79)	34 (30-45)	46 (41-55)	36 (31-45)
Others (<i>n</i> = 12)	86 (58-138)	24 (14-30)	34 (21-45)	25 (14-34)

TAR, Total arch replacement. Figures presented as mean (range).

and ventilation ceased at that time, but the operation proceeded with rapid thoracotomy, manual control of the site of rupture, and internal cardiac massage. Total aortic arch replacement was undertaken successfully and despite the urgency of the procedure, she recovered without any neurologic deficit and was extubated on the third postoperative day. She died on postoperative day 5 of massive gastrointestinal bleeding.

The remaining 17 patients all recovered satisfactorily and were extubated within 48 hours of operation. None required reintubation or special weaning techniques. Mean transfusion requirement for the entire group during the perioperative period was 7.4 units of packed red cells (range 3.0 to 12 units). Fourteen patients received platelet concentrates and fresh frozen plasma. Twelve of the 18 patients received low-dose inotropic support. One patient had sustained elevation of serum creatinine (180 mg/L) greater than preoperative levels, but he maintained a normal urinary output and did not require dialysis. Only one patient sustained a possible neurologic complication (5.6%, range 0.14% to 27%, $p = 0.05$). This 69-year-old woman underwent distal aortic arch and proximal descending thoracic replacement and had isolated weakness of the right arm. Movement was preserved against resistance and the limb was normal within 1 week of operation. A computed tomographic scan showed no abnormality. Although deemed a neurologic event, this could have been related to the position of the arm on the operating table. Two patients who had left recurrent laryngeal nerve palsy preoperatively had persistent hoarseness after the operation. No new phrenic or left recurrent laryngeal nerve palsies occurred as a result of surgery. The mean duration of postoperative hospital stay was 9 days (range 5 to 19 days). None had problems with sternal healing. Thirteen of the 18 patients were discharged in less than 10 days. All 17 hospital survivors are alive and

well after a mean follow-up period of 3.5 years (range 0.2 to 5.6 years).

Discussion

Neurologic injury persists as the single most important source of morbidity and mortality in thoracic aortic surgery.³ Our own experience suggested that retrograde embolism from atheroma or thrombus in the descending thoracic or abdominal aorta can occur with perfusion through the femoral artery. We have also had patients with cerebral infarction from malperfusion through a chronically dissected aorta. Central aortic cannulation is less likely to cause this problem, and we had no evidence for embolic cerebral injury in this small series of patients. Our patient with chronic type B dissection and unsuspected midarch coarctation would almost certainly have had extensive cerebral injury through hypoperfusion had not the antegrade approach been used. Although temporary retrograde venous perfusion of the brain helps remove air or atheromatous debris, embolism may still occur during the cooling and rewarming period. A change of arterial cannula from femoral artery to the vascular graft reduces this risk, but we prefer to avoid the extensive bacterial colonization in the groin if possible.

Our preference for antegrade cerebral perfusion now extends to the combination of aortic root and aortic arch disease. Whereas these cases would previously have been approached by means of femoral arterial cannulation, we now preferentially cannulate the proximal aortic arch. Transesophageal echocardiography can be used to ensure absence of thrombus or friable atheroma at the cannulation site. During circulatory arrest, the cannula is removed and then reinserted into the vascular graft. We find no contraindication to guided cannulation of pathologic aorta that will be excised later. Echocardiography also provides information about the satisfactory position of the cannula tip and docu-

ments effective carotid flow. The method described is applicable to patients with a preexisting ascending aortic graft, but we would selectively perfuse the left subclavian artery in patients with chronic dissection of the ascending aorta.

Extension of the left thoracotomy across the sternum provides access for safe, standard, ascending aortic cannulation, and we have had no morbidity from this incision. Venous return from the right ventricle, as popularized by Kouchoukos, provides excellent flow with expedite cooling and rewarming.⁴ The cannulas are conveniently situated anteriorly away from the main operative field, and access to the aortic arch and descending thoracic aorta is much better than with the sternotomy approach. In particular, the phrenic and recurrent laryngeal nerves are easily identified and preserved. From the patient's standpoint a single operation is preferable to staged aortic arch then descending aortic resection as long as the risks of morbidity are not increased. Up to 50% of our patients may otherwise have been subject to two operations. The method described provides early reperfusion of the cerebral and coronary vessels and thereby allows reconstruction of the descending thoracic or thoracoabdominal aorta without time constraint. We have not observed paraplegia with this method. In contrast, the patient whose brain is illustrated in Fig. 1 underwent total thoracic aortic replacement with aortic root repair through extended left thoracotomy but with femoral cannulation. Retrograde cerebral perfusion as a deairing maneuver failed to prevent severe cerebral damage, which negated an otherwise uneventful procedure.

It is difficult to perform a prospective randomized study to investigate the cerebral protective properties of our pharmacologic cocktail. Such an investigation would require detailed neuropsychologic tests both before and after major thoracic aortic surgery in matched patient groups with many variables. However, from experience with cerebral malperfusion in patients having aortic dissection, we have some anecdotal evidence of benefit. One of our patients with pretreated type A dissection had 15 minutes of normothermic cerebral ischemia before cerebral blood flow was established through the left

ventricular apex but made a complete recovery and returned to work as an accountant. We have not observed excessive bleeding in patients treated with nimodipine, but this calcium-channel blocker is negatively inotropic, and a 10- to 15-minute period of normothermic coronary perfusion may be required before discontinuing cardiopulmonary bypass.^{5,6} We are cautious in our use of aprotinin in cases of profoundly hypothermic arrest. Both hypothermia and aprotinin extend the activated clotting time and prejudice reliable heparin management.⁷ We prefer to infuse aprotinin during the rewarming period of cardiopulmonary bypass in selected patients with pleural adhesions or excessive bleeding on entry.

In summary, this experience with extended left thoracotomy, a central cannulation technique, and single-stage repair of combined arch and descending thoracic aortic conditions illustrates the safety of the method. Duration of both cerebral and myocardial ischemia is relatively short with this approach, and our patients did not experience paraplegia, renal failure (requiring dialysis), or bleeding problems. The ability to visualize and protect the phrenic and recurrent laryngeal nerves contributes to expediting recovery in patients with impaired respiratory function.

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