# Transverse Aortic Arch Aneurysm

## Improved Results of Treatment Employing New Modifications of Aortic Reconstruction and Hypothermic Cerebral Circulatory Arrest

E. STANLEY CRAWFORD, M.D., SALWA A. SALEH, M.D.

**The results of graft replacement for aneurysms involving the entire transverse aortic arch have lagged far behind that achieved for similar lesions located elsewhere. For example, prior to the study reported here, the mortality rate of the former, in our experience, was 25%, whereas it was only 8% for the most extensive forms of thoracoabdominal aortic aneurysms. The difference has been due to limitations and complications of methods employed for cerebral and myocardial protection. The high mortality rate in our patients was due to the deficiencies of temporary bypass graft and cardiopulmonary bypass, and separate brachiocephalic perfusion employed for this purpose. This report is concerned with the use of profound hypothermia for cerebral protection and the application of graft inclusion and direct brachiocephalic arterial reattachment to prevent bleeding in region of operation, as so successfully employed in patients with thoracoabdominal aortic aneurysms. The entire thoracic aorta was involved in four patients, the aortic valve in two patients, coronary artery bypass was performed in two patients, and the pulmonary artery was obstructed in one patient. Employing the techniques described in this report, all eight patients with these extensive lesions survived without complication.**

*From the Departments of Surgery and Anesthesiology, Baylor College of Medicine and The Methodist Hospital, Houston, Texas*

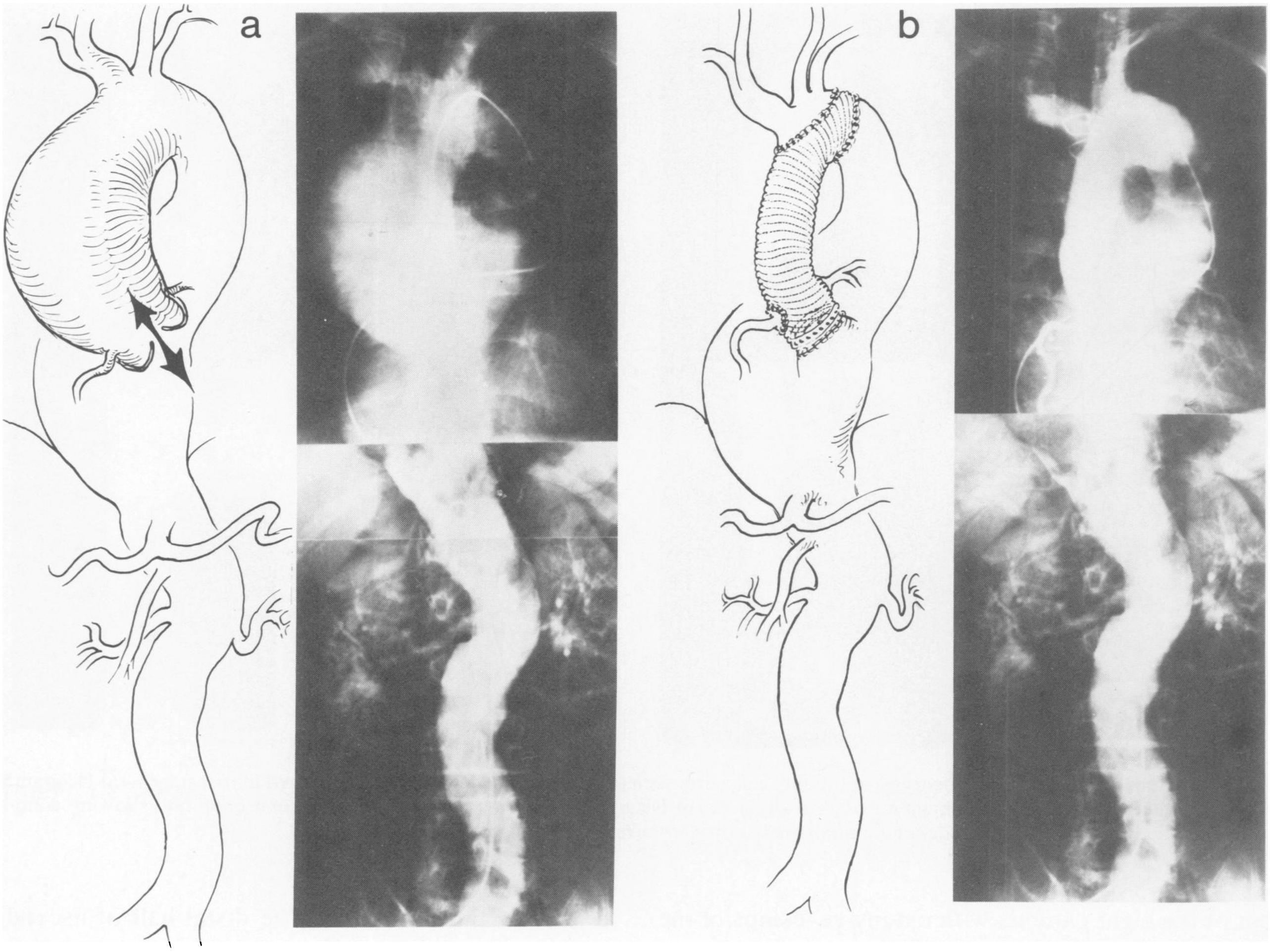
ANEURYSMS OF THE DISTAL transverse aortic arch involving the segment of aorta from which the subclavian artery arises may be treated simply by proximal and distal aortic cross clamping using nitroprusside to control blood pressure and cardiac hemodynamics. Of 26 patients in our series with this type of lesion treated by this method, 25 (96%) survived without neurologic complications, although the left common carotid artery was also clamped in five patients.[2,4] In contrast, the results of treatment in patients with more extensive lesions involving the segment from which both the innominate and left common carotid arteries arise have lagged far behind that obtained in the treatment of aneurysms located elsewhere. The principal difference lies in the need for, the limitations of, and the complications resulting from the methods which have been employed for cardiac and cerebral protection needed during the period of occlusion required for aortic reconstruction. For example, in our series of 20 patients treated with these extensive lesions using temporary or permanent bypass grafting or cardiopulmonary bypass and separate brachiocephalic vessel perfusion as the method of protection, five (25%) died, four from cerebral complications. Both to simplify operation and to afford better cerebral and cardiac protection during operation in these cases, Griepp and associates introduced profound hypothermia and circulatory arrest in 1974.[7] Ott and Cooley presented their experience with this method in six patients with modification in 1978.[11] Although both groups concluded this was a better method, both observed cerebral complications in one case each; however, the most troublesome complication in each experience was bleeding during the warm-up period that in some instances extended into the postoperative period, and was the major cause of death in both series of cases.[6,7,11] To improve our own results in these patients, we have adopted modifications of the techniques of Griepp and Cooley during the past year, and have avoided the problem of bleeding by employing the method of aortic reconstruction, which has proven successful in our experience during the past 15 years in the control of postoperative bleeding in the treatment of thoracoabdominal aortic aneurysms.[3] The purpose of this report is to present this modification of technique and certain observations derived from the successful treat-

Reprint requests: E. Stanley Crawford, M.D., 1200 Moursund Avenue, Houston, Texas 77030.

Submitted for publication: February 10, 1981.

Supported in part by the Joseph W. Moore Cardiovascular Research Fund.

0003-4932/81/0800/0180 $00.95 



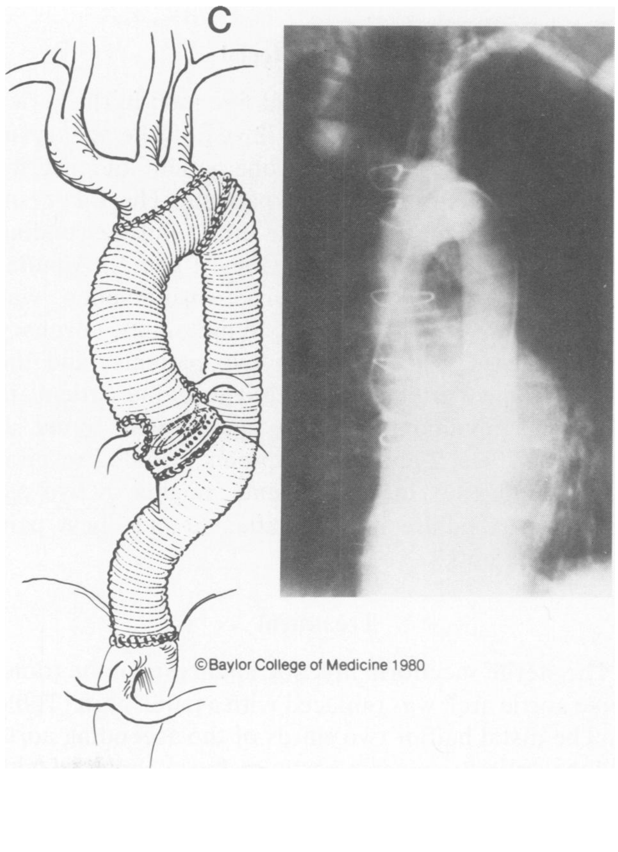




FIG. 1. Illustrations of patient with aortic aneurysm extending from aortic annulus to celiac axis treated by graft-valve composite graft replacement of ascending aorta and transverse aortic arch at one operation and graft replacement of extensive aneurysm of descending thoracic aorta at second operation. (a) Diagram and aortogram made before operation showing extent of aneurysm and aortic insufficiency. (b) Diagram and aortogram made after first operation showing proximal graft and aortic valve in place and functioning. (c) Diagram and aortogram made after second operation showing total replacement of the thoracic aorta and aortic valve with reattachment of coronary and brachiocephalic arteries.

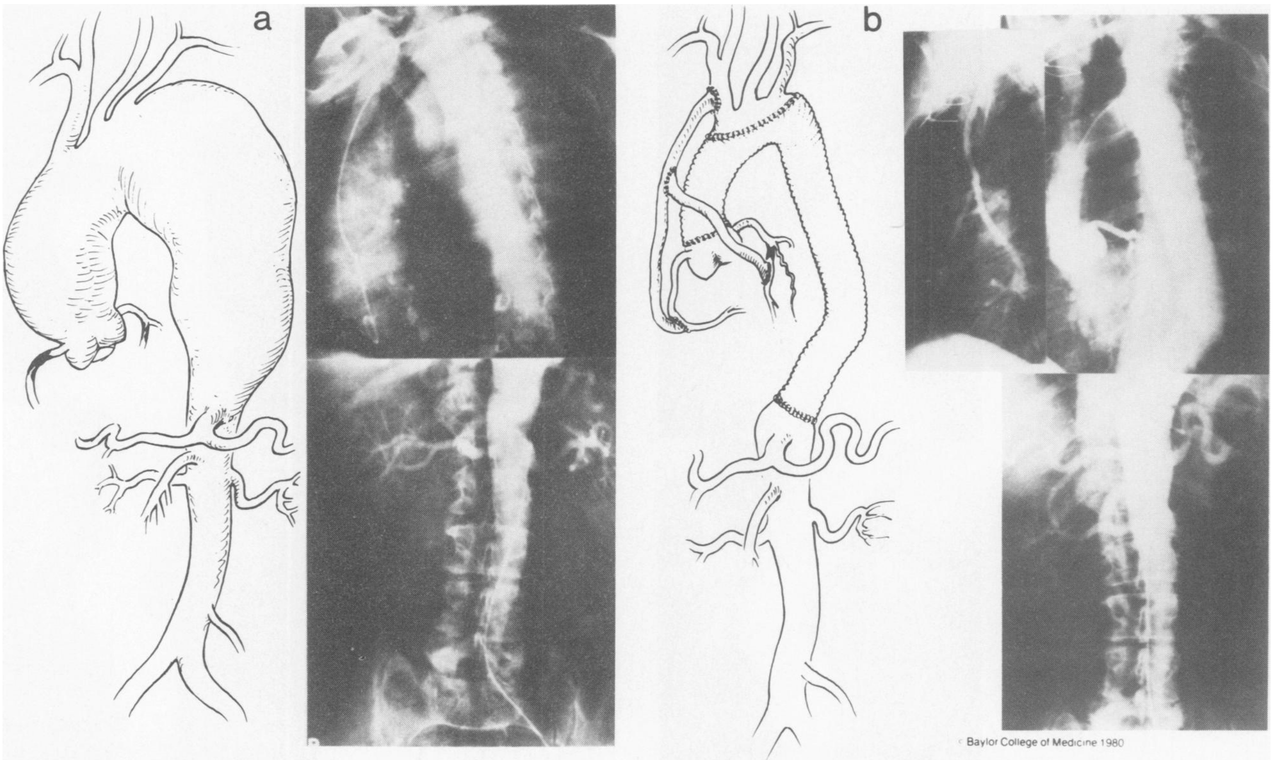



FIG. 2. Illustrations of patient with aneurysm entire thoracic aorta with severe coronary artery disease treated in two stages. (a) Diagram and aortogram made before operation showing extent of disease. (b) Diagram and aortogram made after second operation showing complete replacement of thoracic aorta and functioning innominate coronary artery bypass grafts.

ment of the eight patients with extensive lesions of the aortic arch treated during this time.

## Clinical Material

There were three women and five men in the series whose ages ranged from 51 to 72 years. The aneurysm was mycotic and sacciform in one patient and arteriosclerotic and fusiform in seven patients. The aneurysm involved ascending, transverse arch, and descending thoracic aorta in four patients (Figs. 1 and 2). Annular involvement with severe aortic insufficiency was present in two patients (Fig. 1). Symptomatic coronary artery disease was present in two patients, and the left pulmonary artery was occluded in one patient, in whom aortopulmonary artery fistula was found at operation (Figs. 2 and 3). Symptoms included respiratory insufficiency in two patients, angina in two patients, heart failure in two patients, and chest pain in eight patients.

## Treatment

The sterile sacciform mycotic aneurysm of the transverse aortic arch was replaced with a patch graft (Table 1). The distal half or two-thirds of the ascending aorta and the entire transverse aortic arch was replaced with a graft in three patients. The distal half of ascending aorta and entire transverse arch was replaced and ascending aortocoronary artery bypass graft performed in one patient (Fig. 3). The ascending aorta, all but aortic root, and transverse arch were replaced and innominate artery–coronary artery bypass performed in one patient in whom the descending thoracic aorta was later removed for aneurysm (Fig. 2). The aortic valve, entire ascending aorta, and transverse aortic arch was replaced in two patients using composite valve-graft (St. Jude valve) and descending thoracic aortic aneurysms were replaced in both at a later date (Fig. 1). Resection of the descending thoracic aortic segment involved by aneurysm was deferred until a later day in all four patients with this extensive form of disease. Three of these have returned and the distal segment of aneurysm has been successfully replaced (Figs. 1 and 2).

## Method of Perfusion and Temperature Control

The exposure was obtained through a standard median sternotomy incision. Arterial perfusion was performed through the common femoral artery and venous cannulation made through the right atrium into the superior and inferior vena cava. The left side of the

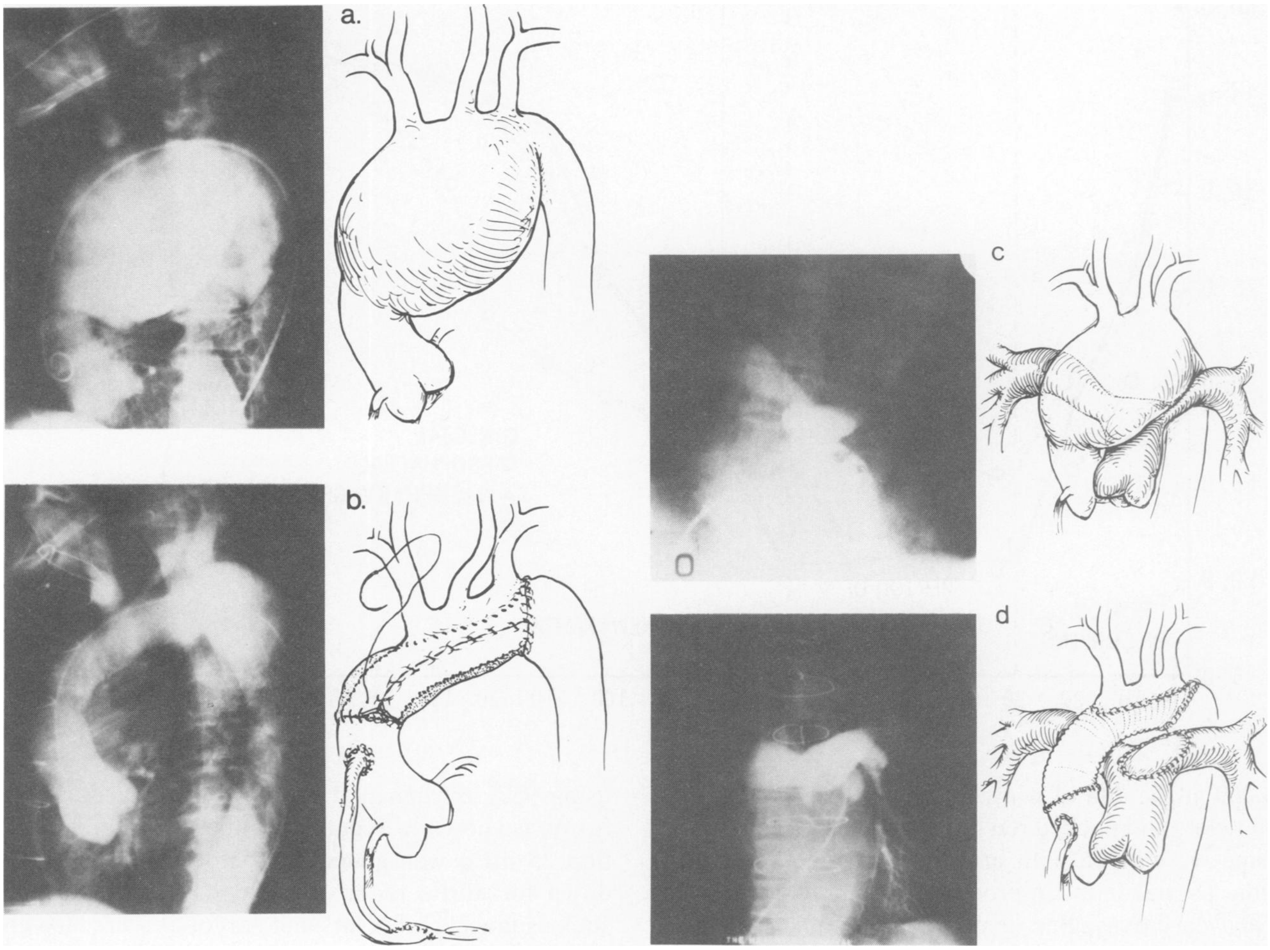



FIG. 3. Illustrations of treatment of patient with coronary artery disease and aneurysm transverse aortic arch producing obstruction left pulmonary artery. (a) Diagram and aortogram showing extent of aneurysm. (b) Diagram and aortogram made after operation showing aortic graft and coronary artery bypass in place and functioning. (c) Pulmonary angiogram made before operation showing compression left pulmonary artery. (d) Pulmonary angiograms after operation showing normal pulmonary arteries and diagram showing method of repair using pericardial patch.

heart was gently sumped through a cannula placed into the left atrium. Perfusion at a rate of 55 cc/kg body weight/minute was performed using a membrane oxygenator system* primed with 20 cc/kg Ringer's lactate solution to which 50–75 g of albumin were added. Heat control was obtained with a disposable hypothermic heat exchanger attached to the venous return system.†‡ Myocardial protection was partially achieved by systemic cooling and intermittent cardiac surface cooling with cold saline solution during operation.

Cooling was begun at the onset of cardiopulmonary bypass at a rate not exceeding one degree per minute, and rewarming started after the great vessels were reattached to graft at a rate not exceeding one degree per three minutes. These speeds of temperature change were rarely achieved. Sodium nitroprusside was given during cooling and rewarming for its vasodilatory effect to promote better perfusion and to reduce skin–core temperature differential. The total pump time, cooling time, cerebral ischemic time, the temperature range during cerebral ischemia, and warm-up times are shown in Table 1. A typical temperature curve during operation, according to sites of measurement, is illustrated by a case shown in Figure 4. Both to prevent cellular sludging and to improve perfusion, hemodilution was maintained between 75% and 70% of normal during operation by monitoring intermittently hemoglobin, hematocrit, and colloidal osmotic pressure levels, and by administration of either Ringer's lactate solution or concentrated red cells and albumin when appropriate (Fig. 5). Platelet counts were usually about 150,000 at onset of perfusion, dropped to about 25,000 during maximum hypothermia, and rose to

* Travenol TMO Oxygenator System.

† 1-5MO338 Travenol, Mortongrove, IL.

‡ 1-5MO343 Travenol, Mortongrove, IL.

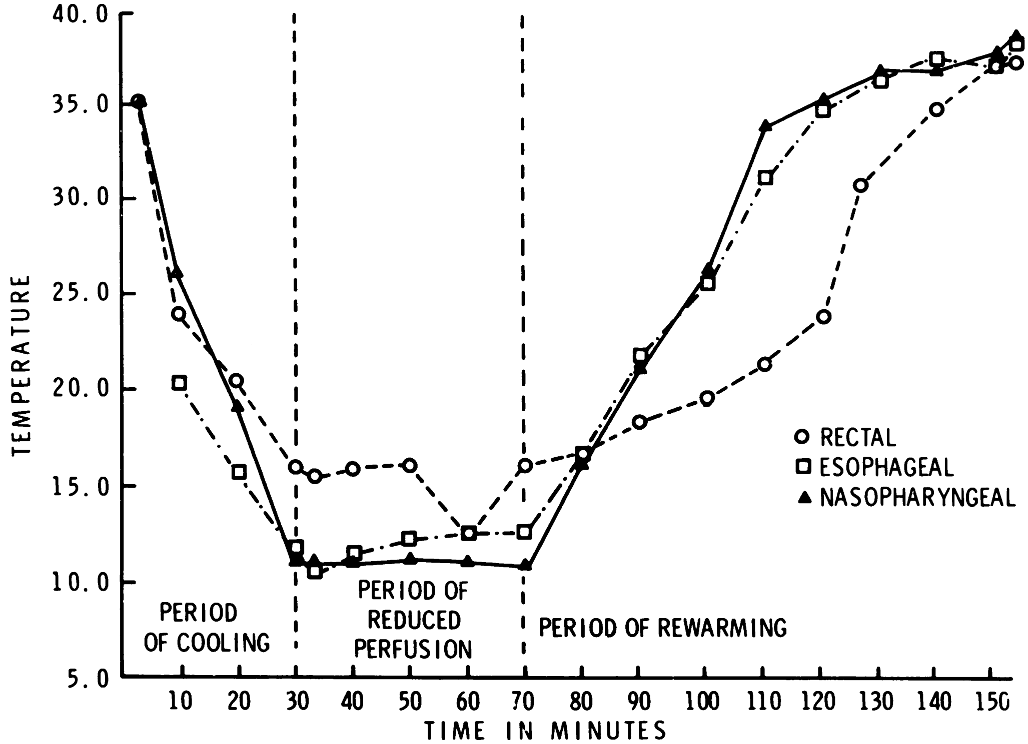



FIG. 4. Typical temperature curve in one patient during operation according to site taken.

120,000 at the end of warm-up; however, 10–12 units of platelets and packed red blood cells and fresh frozen plasma were given with protamine at the end of perfusion as needed, to produce normal clotting and normal cardiovascular hemodynamics of circulation. Acid–base balance during operation with ventilation using 95% oxygen and 5% $CO_2$ mixture during perfusion is shown in Figure 6. Sodium bicarbonate solution 25 mEq was given just before perfusion turned down for aortic reconstruction. Other desired drugs such as muscle relaxants and narcotics were also given at this time.

Summary Aortic Arch Replacement (8 Patients)

| Case | Age/Sex | Operation | Pump Time | Cooling Time* | Cerebral Ischemia Time* | Cerebral Ischemia Temperature† | Warming Time* |
|---|---|---|---|---|---|---|---|
| GL | 60 F | patch repair mycotic aneurysm | 192 | 39 | 26 | 14.9–15.9 (R) | 92 |
| RL | 63 M | replacement arch<br>reattach brachiocephalic vessels<br>innominate-coronary artery bypass | 239 | 54 | 28 | 14.9–15.9 (R) | 111 |
| GB | 59 M | replacement arch<br>reattach brachiocephalic vessels | 167 | 35 | 25 | 20.5–20.8 (R)<br>12.8–13 (E) | 105 |
| HJ | 72 M | replacement arch<br>reattach brachiocephalic vessels<br>aortocoronary bypass | 166 | 33 | 39 | 16–18 (R)<br>12.3–16.4 (E) | 86 |
| GJ | 51 M | replacement arch<br>reattach brachiocephalic vessels | 241 | 40 | 43 | 17.7–18.2 (R)<br>9–11 (E) | 138 |
| BL | 58 M | composite valve-graft arch<br>reattach brachiocephalic vessels<br>reattach coronary arteries | 236 | 59 | 33 | 16.5–17.8 (R)<br>12.8–15.5 (E) | 139 |
| AB | 66 F | replacement arch<br>reattach brachiocephalic vessels | 168 | 36 | 55 | 13.2–17.1 (R)<br>9.7–11.9 (E)<br>9.5–11.1 (N) | 78 |
| LC | 64 F | composite valve-graft arch<br>reattach brachiocephalic vessels<br>reattach coronary arteries | 152 | 31 | 38 | 15.8–16 (R)<br>10.9–12.8 (E)<br>11–12 (N) | 83 |

* Time in minutes.
† Temperature expressed in degrees Centigrade.
(R) Rectal. (E) Esophageal. (N) Nasopharyngeal.

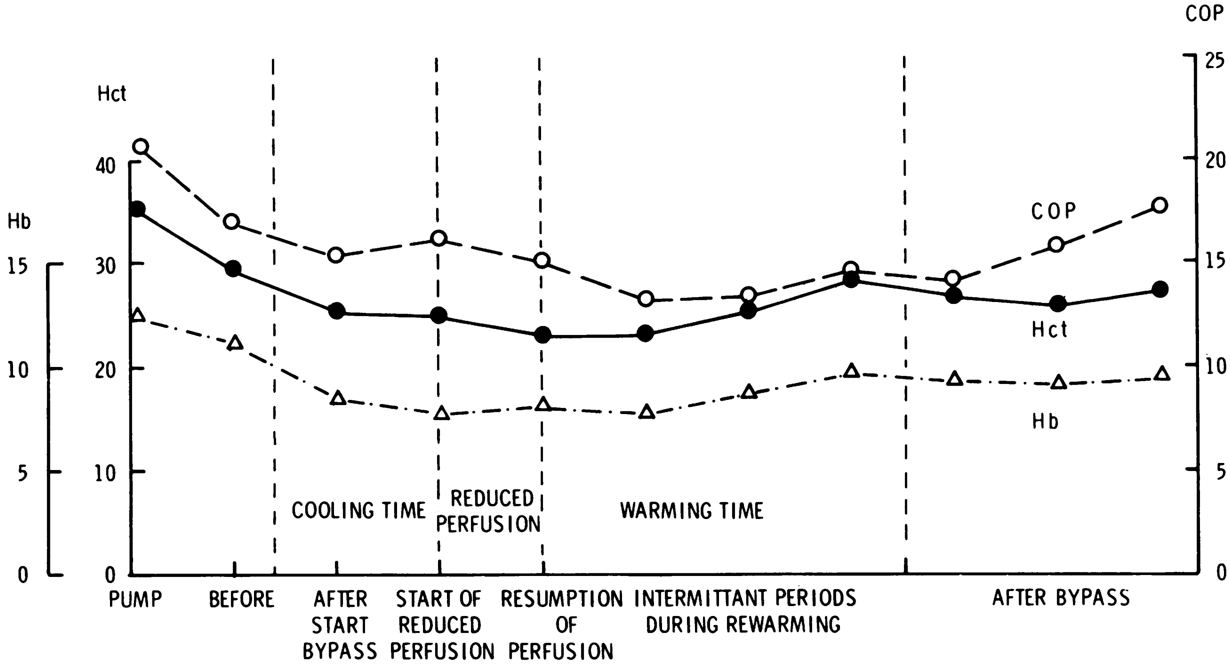



FIG. 5. Hemoglobin, hematocrit, and colloidal osmotic pressure obtained during varying stages of operation showing degree of hemodilution.

### Technique of Reconstruction

Minimal dissection was employed to expose the anterior surface of the ascending aorta and transverse aortic arch. The brachiocephalic arteries were similarly exposed and coronary artery bypass performed in two patients during the period of cooling (Figs. 1 and 3). When the desired level of hypothermia was attained, the head of the table was lowered, the brachiocephalic arteries clamped, and rate of perfusion reduced to 50–150 cc/minute but never stopped (Figs. 7 and 8). The aneurysm was opened longitudinally and the cut edges retracted (Fig. 7a). Thrombi and intimal debris were thoroughly removed from the aneurysmal cavity

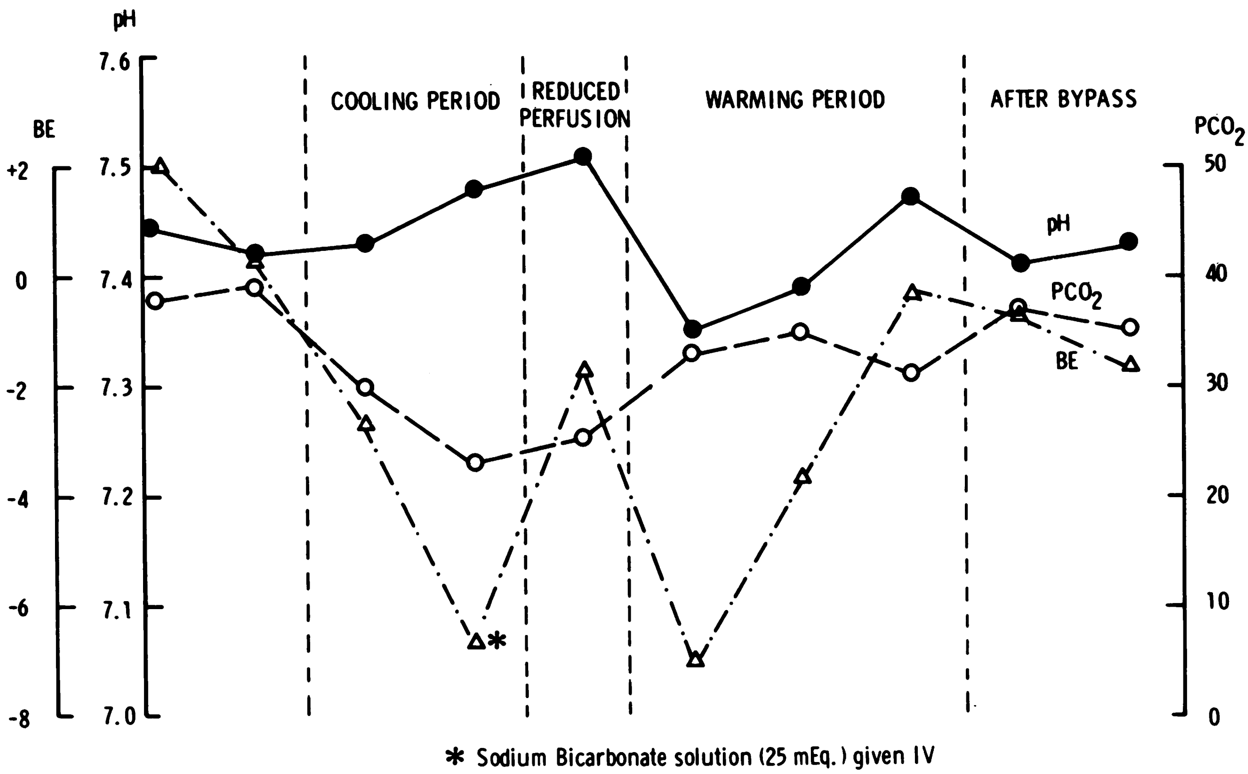



FIG. 6. $Pco_2$, pH, and Base Excess during operation (ventilation using 95% $O_2$ and 5% $CO_2$).

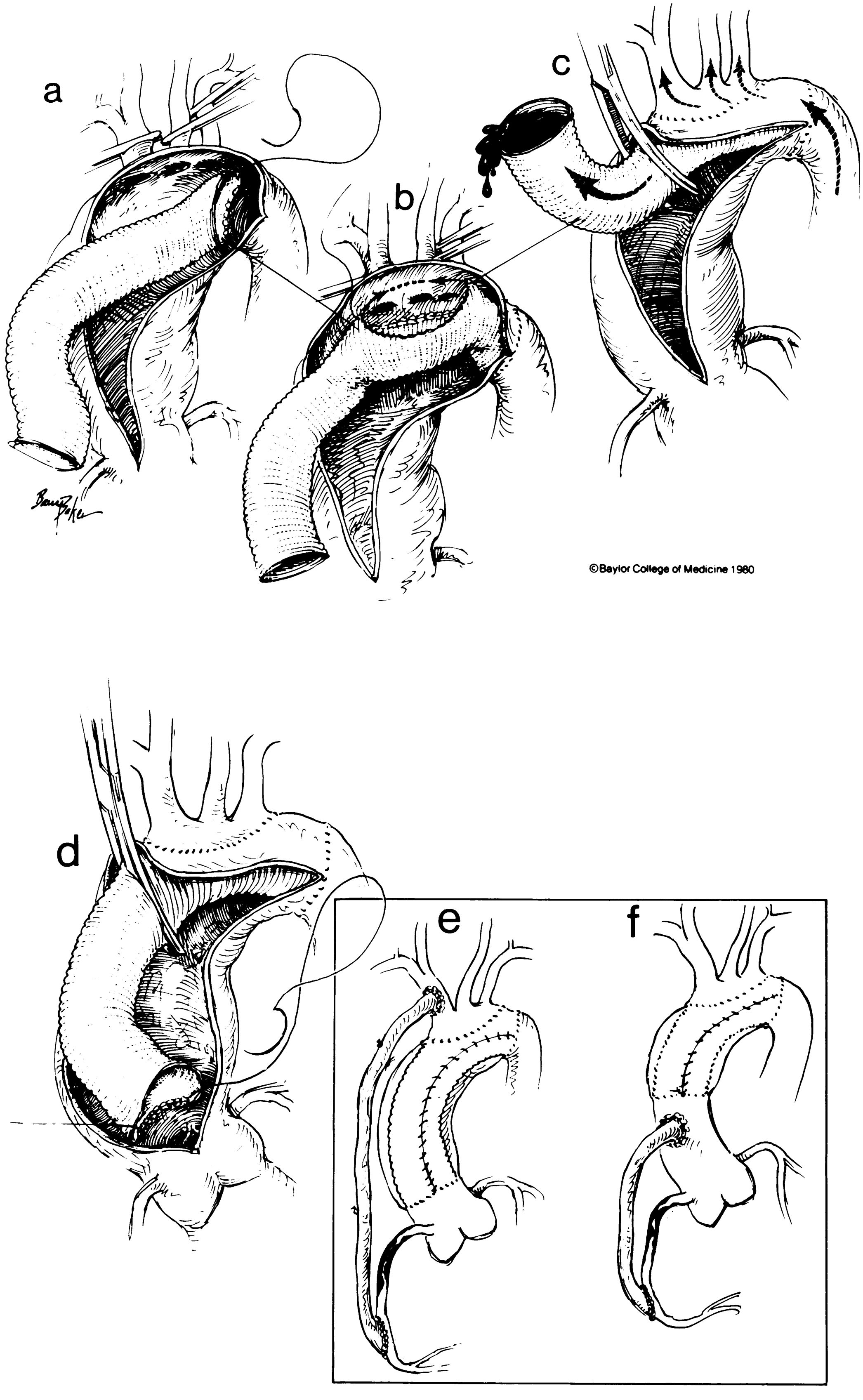



FIG. 7. Drawings showing technique of operation in patients in whom the annulus is not involved. (a) With head down and the brachiocephalic arteries clamped, the aneurysm is opened longitudinally without clamping the aorta. The distal anastomosis is performed after removing all clot and debris. (b) An oval opening is then made in the side of graft and this sutured circumferentially around the origin of the brachiocephalic arteries. (c) With head down, the proximal end of graft is elevated and allowed to fill proximal to origin of brachiocephalic vessels which are unclamped and air massaged into graft. (c-d) The graft is then clamped proximally, full perfusion with rewarming started, and proximal anastomosis completed in same manner as done distally. (e-f) The graft and anastomoses are completely enclosed inside aneurysmal wall. (e) When coronary bypass is performed in patients with extensive aneurysms, the proximal anastomosis is made to side of innominate, subclavian, or common carotid artery and (f) to side of proximal ascending aorta in patients with limited involvement.

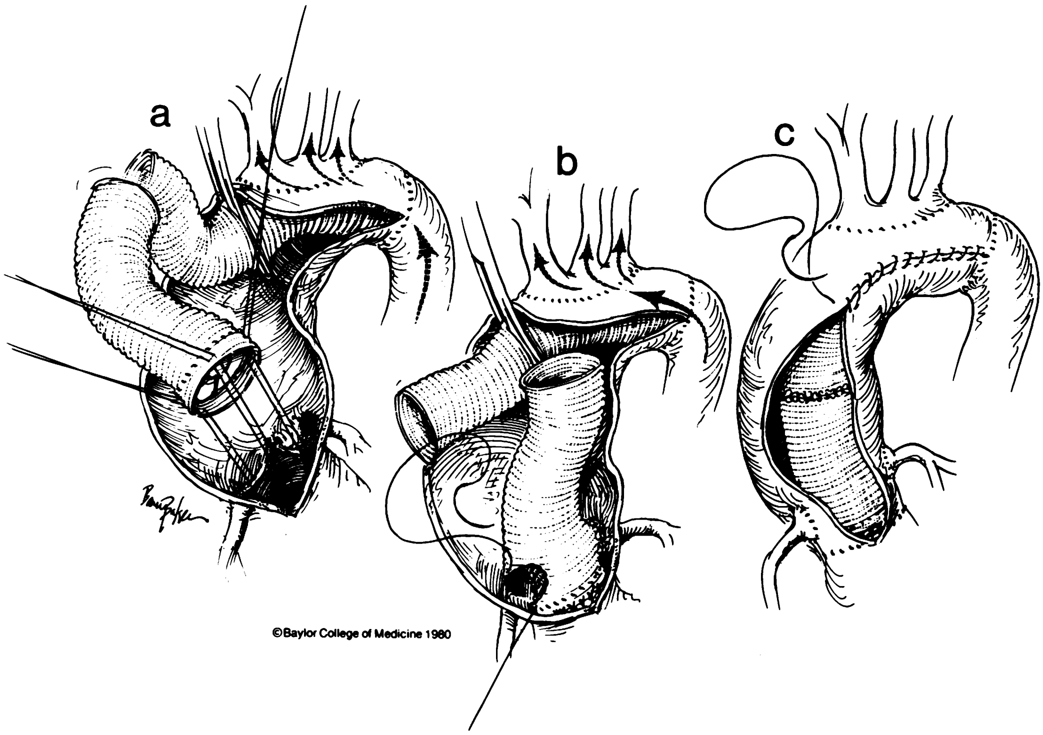



FIG. 8. Drawings showing variation in technique in patients with annular dilatation and aortic insufficiency requiring composite valve-graft replacement. (a) With the distal anastomoses completed and warm perfusion restarted, the aortic valve is replaced with separate composite graft to permit ease of suture. (b) Openings made in the graft are sutured around the origins of the coronary arteries. (c) The two grafts are cut to length and connected by continuous suture. Air is removed in usual manner and graft enclosed tightly inside aneurysmal wall.

and wall. To avoid embolization, spillage proximally into the heart and distally into the open descending thoracic aorta was prevented by first inserting gauze sponge. Aortic clamps were never applied further reducing the possibility of embolization. Debris falling into the brachiocephalic vessels proximal to clamps was removed by saline irrigation. To avoid accumulation of air, the distal aorta was constantly perfused at 50–150 cc/minute and overflow aspirated with sucker. All anastomoses were performed inside the aorta or heart. The distal anastomosis was performed first employing two continuous 4-0 Prolene sutures placed one over the other (Fig. 7a). Suture line bleeding was checked by occluding the graft and increasing the rate of perfusion. Bleeding points were controlled with interrupted suture. The graft was then placed on appropriate tension and an oval opening made opposite origin of the brachiocephalic arteries (Fig. 7b). This opening was sutured circumferentially around these origins with 4-0 Prolene sutures as described for the distal anastomosis and for treatment of thoracoabdominal aortic aneurysms.[3] Suture line bleeding was again checked and secured with interrupted sutures. With the head down and the proximal open end of the graft elevated, the graft was allowed to fill proximal to brachiocephalic origin with blood from slow perfusion (Fig. 7c). The brachiocephalic vessel clamps were removed and these vessels milked proximally. The latter two maneuvers removed air both from the graft and the brachiocephalic arteries. A clamp was then placed across the graft proximal to these vessels, normal perfusion restored, and warm-up begun (Figs. 7c and d and 8a and b). The proximal anastomosis was performed according to extent of aneurysm. When aortic annulus was not involved, the proximal anastomosis was performed to the normal proximal segment of aorta as described for the distal anastomosis using the other end of the graft (Fig. 7d). When the aortic annulus was involved and the aortic valve required replacement because of aortic insufficiency, the aortic valve leaflets were removed and a separate composite valve-graft (St. Jude valve) was attached to aortic annulus employing interrupted 3-0 Dacron® sutures (Figs. 8a–c). Openings were made in the graft and sutured around the coronary ostia using 4-0 Prolene sutures (Fig. 8b). The proximal composite graft and distal graft were cut to length and joined end to end using 3-0 prolene suture (Fig. 8c). Prior to completion of this anastomosis, the heart and graft were allowed to fill with blood, the anastomosis completed, the distal clamp removed restoring coronary artery circulation, the apex of left ventricle aspirated, and the graft vented with #18 gauge needle to remove residual air. Gentle left-sided sumping was resumed until good cardiac output was restored.

Regardless of method employed for proximal anastomosis, the cut edges of the aneurysmal wall were sutured snugly around the entire region of reconstruction using 3-0 Prolene sutures completely enclosing the graft and anastomoses within the old aortic channel (Figs. 7e and f and 8c). This step in the operation produced a watertight closure and produced complete hemostasis in the region of aortic operation and eliminated bleeding during the remaining period of operation. To avoid break in this seal, special consideration was given to the site of proximal anastomosis of the vein graft in the two patients requiring coronary artery bypass. The proximal anastomosis was performed to the side of the uninvolved ascending aorta in one patient (Figs. 3b and 7f) and to the side of the distal innominate artery in the other patient in whom all of the available ascending aorta was involved (Figs. 2 and 7e).

## Results

All patients regained consciousness on the day of operation and survived operation without complication. Heart failure, angina, respiratory failure, aortic insufficiency, and chest pain were relieved. All patients were studied angiographically prior to discharge from the hospital and all anastomoses were found intact; the coronary bypasses were patent; and the aortic valves were competent. Of the four patients with distal extension of aneurysm into descending thoracic aorta, three returned six to eight weeks after operation and had successful uncomplicated graft replacement by techniques previously described.[4] Aortograms made before and after this second operation showed no vascular complications associated with either operation (Figs. 1 and 2).

## Discussion

The method of treatment employed in this small series of extensive and complicated cases of arch aneurysms proved to be very successful both because of its simplicity and because it safely protected the vital organs including brain during the period of aortic reconstruction. Bleeding during and after operation was well controlled by the reconstructive procedure which combined when necessary the techniques of proximal reconstruction using composite valve-graft established by Bentall, Edwards, and Kouchoukos with the method of graft inclusion and major vessel reattachment which we have employed in the treatment of thoracoabdominal aortic aneurysms.[1,3,5,9] Innominate, common carotid, and subclavian artery attachment of proximal end of coronary artery bypass graft, as first performed by Howell, permitted easy bypass without losing important effects of aortic graft inclusion.[10] Staging of operation in patients with extensive lesions involving the entire thoracic aorta was an asset in these cases. Proximal operation was more easily performed through midsternotomy incision, and associated cardiac problems conveniently corrected, permitting later aortic reconstruction for the descending thoracic aortic component of aneurysm with better exposure through a posterolateral incision, and at a time when good cardiac function had been restored. Good perfusion, careful frequent monitoring of physiologic changes, and appropriate reaction to these changes were of great importance. To be sure, this experience is small but includes the numerous variations of the clinical problems imposed by the disease; and as a result of the effectiveness with which therapy could be successfully adapted to all of them, we plan to adopt it as the routine method of operation.

## Acknowledgments

We wish to thank Mr. Barry Baker for his illustrations and Mr. and Mrs. Gary Cornelius for their perfusion support.

## References

1. Bentall H, DeBono A. A technique for complete replacement of the ascending aorta. Thorax 1968; 23:338.
2. Crawford ES, Saleh SA, Schuessler JS. Treatment of aneurysm of transverse aortic arch. J Thorac Cardiovasc Surg 1979; 78:383.
3. Crawford ES, Snyder DM, Cho GC, Roehm JOF, Jr. Progress in treatment of thoraco-abdominal and abdominal aortic aneurysms involving celiac, superior mesenteric, and renal arteries. Ann Surg 1978; 188:404.
4. Crawford ES, Walker HSJ, III, Saleh SA, Normann NA. Graft replacement aneurysm descending thoracic aorta: results without bypass or shunting. Surgery 1981; 89:73.
5. Edwards SW, Kerr AR. A safer technique for replacement of the entire ascending aorta and aortic valve. J Thorac Cardiovasc Surg 1970; 59:837.
6. Ergin MA, Griepp RB. Progress in treatment of aneurysms of aortic arch. World J Surg 1980; 4:535.
7. Griepp RB, Stinson EB, Hollingsworth JF, Buehler D. Prosthetic replacement of the aortic arch. J Thorac Cardiovasc Surg 1975; 70:1051.
8. Javid H, Hulian OC, Dye WS. Complications of abdominal aortic grafts. Arch Surg 1962; 85:650.
9. Kouchoukos NT, Karp RB, Lell WA. Replacement of the ascending aorta and aortic valve with a composite graft: results in 25 patients. Ann Thorac Surg 1977; 24:140.
10. Lefrak EA, Howell JF. Successful surgical management of acute retrograde dissection of the aorta during coronary artery bypass. J Thorac Cardiovasc Surg 1972; 63:149.
11. Ott DA, Frazier OH, Cooley DA. Resection of the aortic arch using deep hypothermia and temporary circulatory arrest. Circulation 1978; 58:I-227.

## Addendum

Since this manuscript was submitted, nine additional patients with aneurysms of the aortic arch have been submitted to operation employing the techniques described in this paper. Of these, seven survived without complication; one developed multiple emboli from aortic intimal debris to brain and right axillary artery 9 hours after operation and died 7 days later. The other patient died the day of operation from dissection descending thoracic aorta.