Controlled Extracorporeal Circulation in Surgical Treatment of Aortic Aneurysm *

DENTON A. COOLEY, M.D., MICHAEL E. DEBAKEY, M.D.,
GEORGE C. MORRIS, JR., M.D.**

DURING the six years which have elapsed since excisional therapy of aortic aneurysm was advocated as the surgical procedure of choice in all patients in whom conditions permitted operation, considerable progress has been made in the application of this method of treatment.[3] Of particular significance has been improvement in methods of aortic replacement and in effective control of certain limiting factors which at first were considered to be serious obstacles in the application of this method in certain anatomic locations of the aorta. The aorta obviously provides a vital function which cannot be suddenly interrupted for appreciable periods without producing serious or even fatal consequences. Certain anatomic regions of the aorta are more critical than others in this regard depending primarily upon the proximity to the heart. Accordingly the ascending aorta is more critical than the segment of abdominal aorta below the origin of the renal arteries. Thus, whereas temporary occlusion of the abdominal aorta may be tolerated for periods in excess of two hours without significant ischemic damage to distal tissues, occlusion of the ascending aorta for brief periods of even a few minutes results in death from cardiac strain or brain damage. Excisional treatment of aneurysms of the thoracic aorta has therefore been a particularly difficult and challenging problem since control of these factors is necessary for the success of operation.

In general two prime considerations exist in temporary occlusion of the thoracic aorta, namely the effect of the increased vascular resistance upon the heart and the ischemic effect upon the brain and spinal cord.[4] Most attention has been focussed upon the latter since until recently fusiform aneurysms of the ascending aorta and proximal aortic arch were considered to be nonresectable because of the problem associated with aortic occlusion at this anatomic level. Prevention of central nervous system damage during aortic resection has been achieved by several methods. Induced general body hypothermia reduces the metabolic requirements of the spinal cord or brain and apparently prolongs the safe period of aortic occlusion. Our own experimental and clinical experience with hypothermia in aortic surgery demonstrated the effectiveness of this modality in preventing neurologic sequelae.[5, 19, 20] Nevertheless, there are several well recognized disadvantages of hypothermia which limit its usefulness, including certain cardiac, pulmonary, and hematologic complications. In addition, the procedure of cooling and rewarming the patients, many of whom are elderly and in poor general condition, may increase the risk of the operation. The other method employed is concerned with various types of temporary intraluminal and extraluminal shunts to provide circulation to the distal segment during periods of aortic occlusion. Our own experience with this method has

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** From the Cora and Webb Mading Department of Surgery, Baylor University College of Medicine, and the surgical services of the Methodist, Jefferson Davis, and Veterans Administration Hospitals, Houston, Texas.

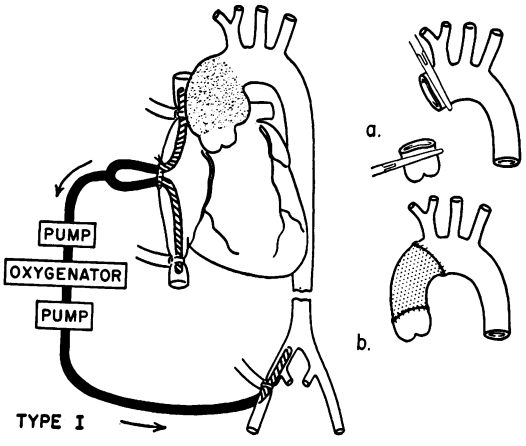

FIG. 1. Drawing showing method of cardiopulmonary bypass used in resection of aneurysms of the ascending aorta.

been mostly in its application to resection of aneurysms involving the aortic arch and the proximal abdominal aorta.[6, 11] Shunts of large caliber sutured into the proximal ascending aorta and connected with the descending aorta made it possible to cross clamp the ascending aorta controlling left ventricular strain and at the same time providing circulation in the distal aorta. Side shunts into the carotid arteries provided cerebral circulation so that the entire arch could be removed and replaced with a graft. Another use for shunts was found in aneurysms of the proximal abdominal aorta where the large caliber bypass was used primarily to minimize the period of total renal ischemia to prevent renal complications after aneurysmectomy. Although shunts have been used effectively in aortic surgery certain disadvantages exist which justify a search for a better method. For example the proximal aorta or subclavian artery may not be suitable or accessible for insertion of shunts of sufficient size. Furthermore there is no means of determining the volume of flow through the shunts during the period while the parent vessel is occluded.

With the recent demonstration of the clinical feasibility of controlled extracorporeal circulation in surgical treatment of intracardiac lesions we have employed this concept during the past year in order to overcome some of these technical problems.[7, 8] This report is concerned with our experience with 32 cases of aortic aneurysm in which temporary aortic bypass was used incorporating a Sigmamotor pump to measure the rate of flow through the circuit.

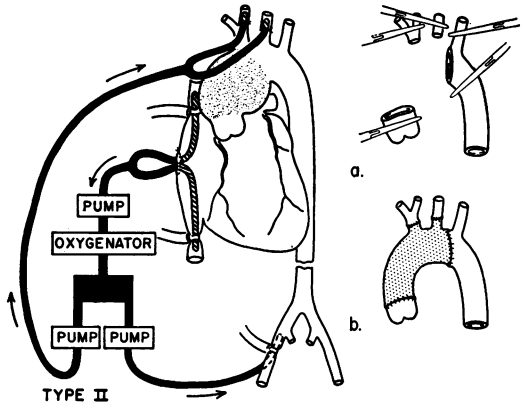

FIG. 2. Drawing showing method of cardiopulmonary bypass and carotid artery perfusion used in resection of aneurysms of the transverse aortic arch.

METHOD

Two methods of extracorporeal circuit were employed in operations upon these patients, one which involved bypassing the heart and lungs as well as a segment of aorta and the other consisting essentially of bypassing only a segment of aorta while oxygenation of blood was performed by the patient's own lung. When cardiopulmonary bypass was necessary in order to resect an aneurysm located in the aortic arch a pump oxygenator system was employed (Fig. 1). The apparatus was a modified DeWall-Lillehei system with a bubble diffusion oxygenator.[9, 13] Venous blood was removed from plastic cannulae $\frac{3}{16}$ inch internal diameter inserted in the superior and inferior venae cavae, pumped through the oxygenator, and returned through a cannula

in the common femoral artery. Flow rates of approximately 35 cubic centimeters per kilogram body weight were used. Immediately before the perfusion was started Heparin 1.5 milligrams per kilogram body weight was administered to the patient and upon completion of the perfusion a similar amount of Protamine sulfate was administered. Exposure of the aortic arch for resection was obtained through a bilateral third intercostal space incision transecting the sternum. When the location of the aneurysm required temporary occlusion of the carotid circulation perfusion of the individual carotid arteries was employed introducing between 250 and 400 cubic centimeters of oxygenated blood per minute into each artery (Fig. 2). For this purpose a separate Sigmamotor pump was used to pump oxygenated blood from the reservoir to the carotid cannulae. Usually these cannulae were small #10 or #12 French polyvinyl plastic catheters so that no obstruction to the normal carotid flow was produced prior to clamping the carotid or innominate artery at the level of the aortic arch. Carotid cannulation was done in the upper mediastinum or through separate small transverse cervical incisions to expose the carotid vessels in the neck. In instances where occlusion of the left subclavian artery was necessary no circulation in the left vertebral artery was present during the period of aortic resection, but usually the right subclavian and vertebral artery were being perfused retrograde through the right carotid and innominate arteries.

For aneurysms arising distal to the point of origin of the left common carotid artery a left postero-lateral thoracotomy incision was made in the fifth intercostal space or lower with the patient in the lateral position (Fig. 3). In these cases oxygenated blood was removed proximal to the point of occlusion by a cannula placed in either the left subclavian artery, the left auricular appendage, or a pulmonary vein (Figs. 4, 5, 6). The pulmonary vein was used in two

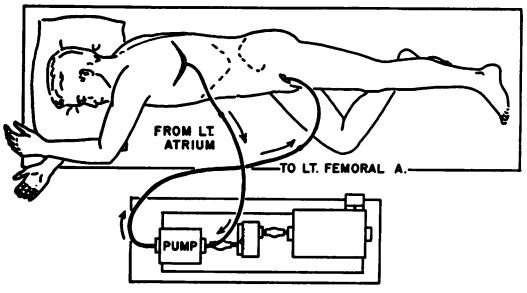

FIG. 3. Drawing showing position of patient on operating table and method of controlled extracorporeal circulation for aneurysms of descending thoracic aorta.

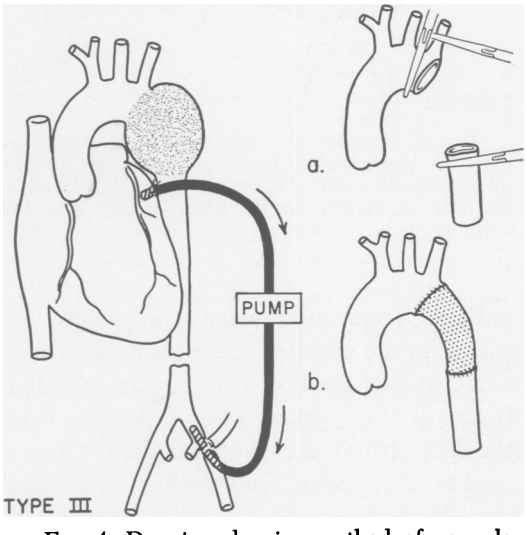

FIG. 4. Drawing showing method of cannulation of left auricle and left common femoral artery for aortic bypass used in aneurysms extending into distal portion of aortic arch which required aortic occlusion proximal to left subclavian artery.

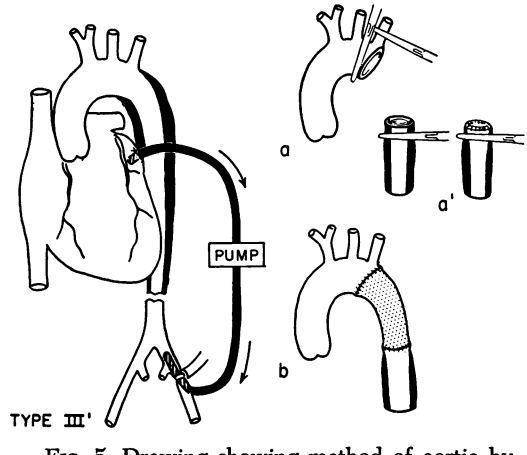

FIG. 5. Drawing showing method of aortic bypass and technic of resection employed in acute dissecting aneurysms of descending thoracic aorta.

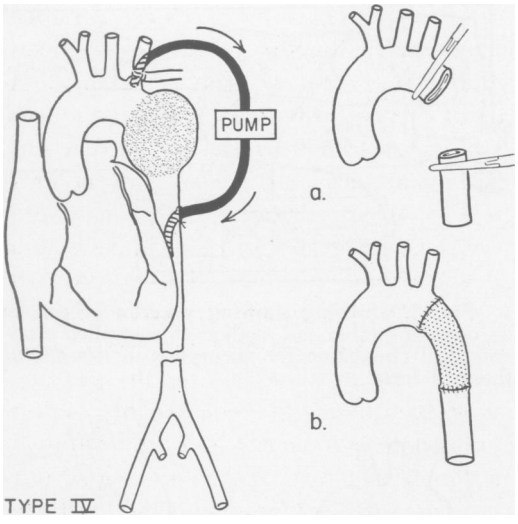

FIG. 6. Drawing showing method of aortic bypass for resection of fusiform aneurysms of the descending thoracic aorta using cannulae placed in the left subclavian artery and directly into the aorta.

patients, but pulmonary congestion occurred in the corresponding pulmonary segment so this method is not recommended. Removal of oxygenated blood directly from the left atrium was well tolerated from a cardiac standpoint, and since this method was relatively simple to employ, it was considered the method of choice in most instances. The blood removed through the proximal cannula was passed through a single Sigmamotor pump and returned to the arterial system distally through a cannula inserted directly into the aorta or through a cannula inserted into the left common femoral artery. A catheter in the femoral artery was the preferred method of returning blood to the aorta, and for this purpose a $\frac{3}{16}$ inch plastic tube was threaded upward into the common iliac or abdominal aorta to provide an adequate flow to protect the spinal cord and abdominal viscera during the period of aortic occlusion. No standard rate of flow was used in all cases of this type, but in most instances a rate of 20 cubic centimeters per kilogram body weight per minute which produced a total flow of 1,200 to 1,500 cubic centimeters per minute was used. In actual practice, however, the rate of flow was adjusted to the blood pressure in the segment of aorta above the aortic clamp attempting to maintain systolic pressure in this segment during the occlusion period approximately 10 to 30 millimeters Hg above normal pressure. Accordingly from time to time during the period of occlusion the rate of flow was adjusted to compensate for fluctuations in blood pressure varying in the range of 800 and 2,000 cubic centimeters per minute. Before the extracorporeal system was connected to the patient Heparin 1.0 milligram per kilogram body weight was administered intravenously and after the graft was inserted and perfusion discontinued a counteracting dose of Protamine sulfate was administered. The blood remaining in the plastic tubes at the completion of the bypass was pumped back into the patient through the femoral cannula after which the openings in the left auricular appendage and common femoral arteries were repaired.

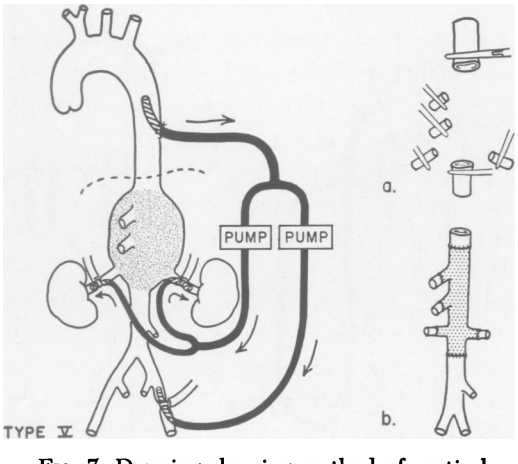

FIG. 7. Drawing showing method of aortic bypass used for aneurysms of the lower thoracic and proximal abdominal aorta showing perfusion of renal arteries with a separate pump.

For aneurysms involving the proximal abdominal aorta which include the renal arteries the extracorporeal circuit using a Sigmamotor pump was also used (Fig. 7).

A thoraco-abdominal incision was made through the eighth intercostal space with the patient in a semi-lateral position and dividing the costal margin. The proximal cannula was inserted directly into the aorta above the upper clamp and secured in place with mattress sutures. Blood was returned distally through a plastic cannula inserted into the common femoral artery. If the renal arteries themselves were clamped, renal perfusion through #8 French plastic catheters was employed using another Sigmamotor pump in a manner similar to carotid perfusion, and a flow rate of approximately 75 cubic centimeters of blood per minute into each kidney was used (Fig. 7). Heparin and Protamine sulfate were administered in the same dosage as for aneurysms in the descending thoracic aorta.

RESULTS

During the past year 32 patients with aneurysms of the thoracic aorta were operated upon using controlled extracorporeal circulation as described above. Since the risk of operation depends primarily upon the location and nature of the lesion, it is proper to consider the results in separate categories.

Aneurysms of the Ascending Aorta and Arch: Among the ten patients operated upon for aneurysm of the proximal aorta and arch there were two patients surviving and well, one and eight months respectively after operation. Five patients died in the first week after operation, and three deaths occurred more than one week after operation. One death ensued six weeks later from hemorrhage after the patient had made an initial good recovery from operation. Ages in this group of patients varied between 27 and 64 years, and the ages of the survivors were 50 and 56 years respectively. Age was not considered a contraindication to operation, but it may be significant that none of the three patients who were more than 60 years of age survived. Temporary occlusion of the ascending aorta produces a radical change in the functional status of the heart. Maintenance of myocardial viability undoubtedly depends upon adequacy of coronary circulation even though cardiac output is temporarily suspended, and the presence of arteriosclerotic changes may prevent recovery from operation. In patients of advanced age this type of operation will always impose a significant hazard. In several of these patients the aneurysm arose so close to the aortic valve that the proximal aortic clamp actually occluded the ostia of one or both coronary vessels, and the myocardium was totally deprived of blood during the period of resection and graft replacement. Cardiac arrest occurred in these patients within a few minutes and persisted until the occluding clamp was released. In only one instance was it impossible to restore a sinus rhythm, although ventricular fibrillation requiring electric shock occurred in three other patients. Failure to resuscitate the heart in one patient was attributed to extensive coronary sclerosis and obliterative changes. If the proximal aortic clamp could be applied 2.0 centimeters or more above the aortic valve, coronary circulation appeared to continue throughout the period of resection, and a sinus rhythm remained for as long as one hour in some cases. After the aortic occlusion was released in these cases, sinus rhythm was usually maintained although ventricular fibrillation occurred in two and was corrected with electric shock.

One unique case deserves separate mention since it reveals the wide variation among patients and organs in response to anoxia and ischemia. The patient was a 64-year-old Latin-American male in chronic congestive heart failure with a massive perforated syphilitic aneurysm of the proximal aortic arch producing total atelectasis of the left lung from bronchial compression (Fig. 8). The aneurysm had eroded the anterior chest wall producing a pulsatile mass in the left pectoral region 10 centimeters above

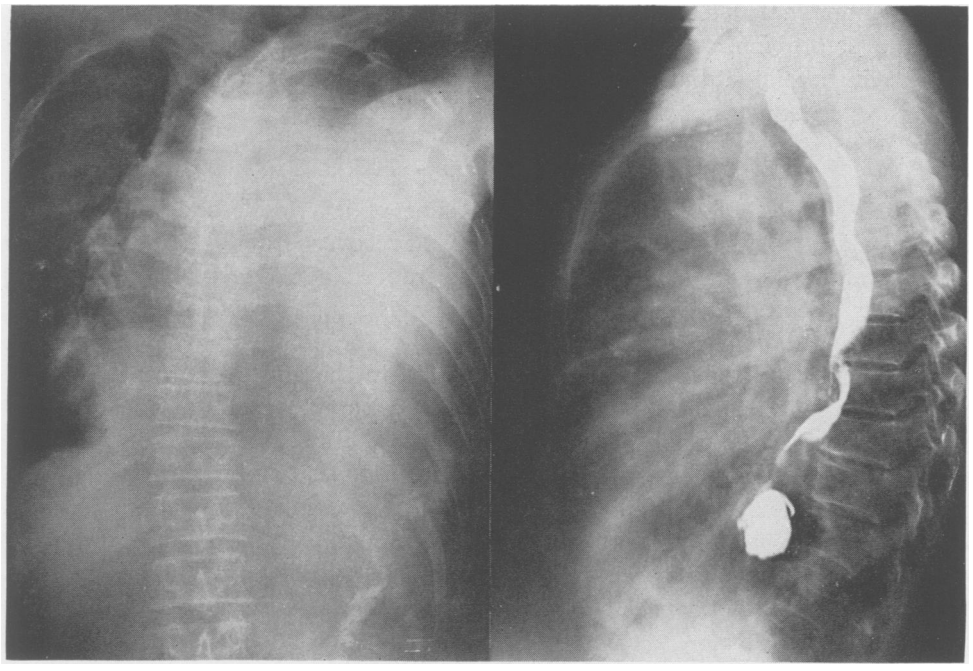

FIG. 8. Roentgenograms of chest in postero-anterior (a) and lateral (b) projections in 64-year-old patient showing massive aortic arch aneurysm producing atelectasis of left lung and extreme displacement of trachea and esophagus.

the usual skin level. Cardiopulmonary bypass was instituted, and the ascending aorta proximal to the aneurysm was clamped (Fig. 9a and b). Because of the dense fibrous reaction and organizing hematoma around the transverse aortic arch it was impossible to place a clamp distal to the lesion. Thus, the pump oxygenator was turned off, and the aneurysm was opened widely to expose the ostium in the distal portion of the aneurysmal cavity (Fig. 9b). A knitted nylon-dacron tube graft was sutured into the distal aortic opening using continuous black silk sutures. A clamp was placed on the prosthesis proximal to the anastomosis, and the pump oxygenator was started again after ten minutes of complete circulatory arrest (Fig. 9c). The proximal anastomosis was performed and the ascending aorta released 30 minutes after the aorta was first occluded (Fig. 9d). During the entire period even when the pump oxygenator was not functioning the heart in this 61-year-old patient retained a sinus rhythm and after operation for the first four or five days no evidence of cardiac failure was detected. Of even greater interest is the fact that the patient regained consciousness promptly after operation and was mentally clear until the seventh day when he died in cardiac failure. This case demonstrated in a striking manner that tolerance to anoxia and ischemia by the central nervous system and myocardium may vary widely and that accepted concepts of susceptibility of body tissues to anoxia are not absolute in the individual case.

Morbidity and mortality of operation for aneurysm of the aortic arch are influenced not only by the technical problems concerned with excision of lesions in this vital region, but also by the many complications which affect cardiopulmonary bypass and the mechanical pump oxygenator. For ex-

ample, hemorrhagic manifestations were responsible for the death of two of these patients, and such complications are more common after operations using a pump oxygenator. Thus, for these and other reasons the risk involved in such procedures may continue to be high for some time until these factors can be adequately controlled, but the excellent results in the two survivors provide a gratifying stimulus to the pursuit of this difficult problem. Follow up on the 50-year-old patient operated upon eight months ago with resection of the entire ascending aorta for aneurysm reveals a normally functioning homograft, and the patient has returned to full activity [7] (Fig. 10).

Fusiform Aneurysms of Descending Thoracic Aorta: In this category there were ten patients with aneurysms of the aorta arising distal to the origin of the left common carotid artery and in which a single pump was used for temporary aortic bypass. Death resulted from pulmonary edema and congestive heart failure on the third day after operation in one 63-year-old patient and from coronary occlusion one week after operation in another 61-year-old patient. Two of the patients in this group had traumatic aneurysms of large size due to blunt injury and occurring in the typical location for such lesions, i.e., in the aortic isthmus distal to the left subclavian artery. Both of these patients were males, 44 and 48 years of age, and survived operation without complication. Four other patients had extensive aneurysms of the descending thoracic aorta requiring resection of practically the entire descending thoracic aorta (Figs. 11–13). Since we,[4] like others [1, 14] have emphasized the risk of severe spinal cord damage causing death and paraplegia following replacement of the entire descending thoracic aorta, it was particularly gratifying that all survived operation and none had serious neurologic sequelae. The distal anastomosis in these four patients was just above the aortic hiatus of the diaphragm. Yet one must not take the experience with successful replacement of extensive segments of descending thoracic aorta to indicate that the studies on blood supply to the cord are incorrect and that the entire descending thoracic aorta may always be resected with safety. It does, however, suggest strongly that the method of extracorporeal circulation has a definite protective effect against neurologic damage under these circumstances. Considerable variation unquestionably exists among patients in tolerance of the spinal cord to temporary aortic occlusion due to many factors including the anatomic pattern and segmental distribution of spinal arteries.[1, 14] For example, in one 48-year-old patient operated upon recently rupture of a fusiform aneurysm of the aorta located just distal to the left common carotid artery occurred during the initial dissection. The aorta distal to the

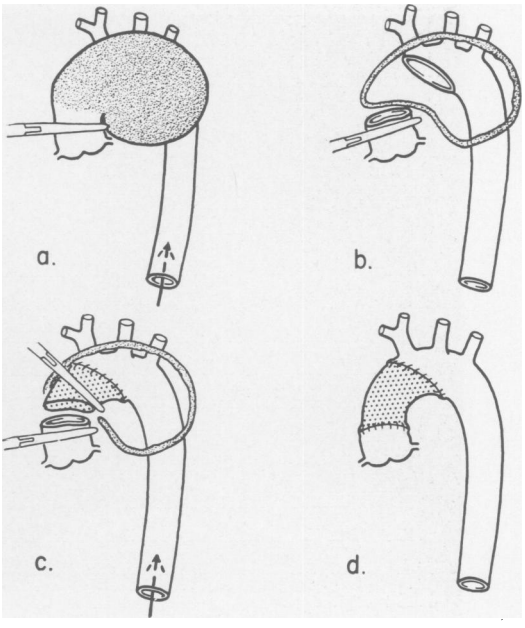

FIG. 9. (a, b, c, d). Drawings showing stages in operation using cardiopulmonary bypass for resection of massive aneurysm shown in Figure 8. During stage *b* the pump oxygenator was discontinued temporarily for ten minutes, yet the patient suffered no apparent neurologic damage.

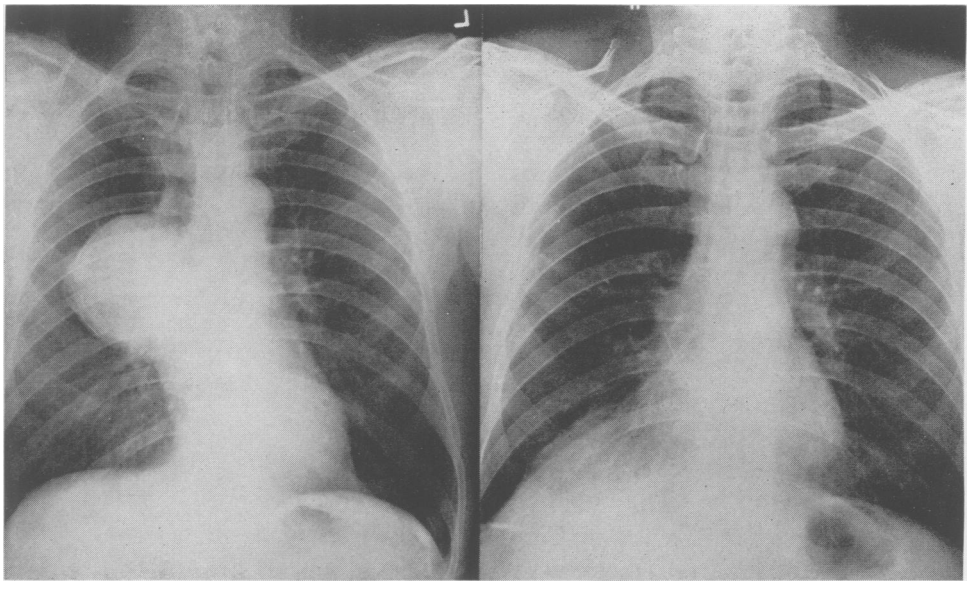

FIG. 10. Roentgenograms of chest in 50-year-old patient with aneurysm of ascending aorta made before operation (a) and eight months after resection and homograft replacement (b).

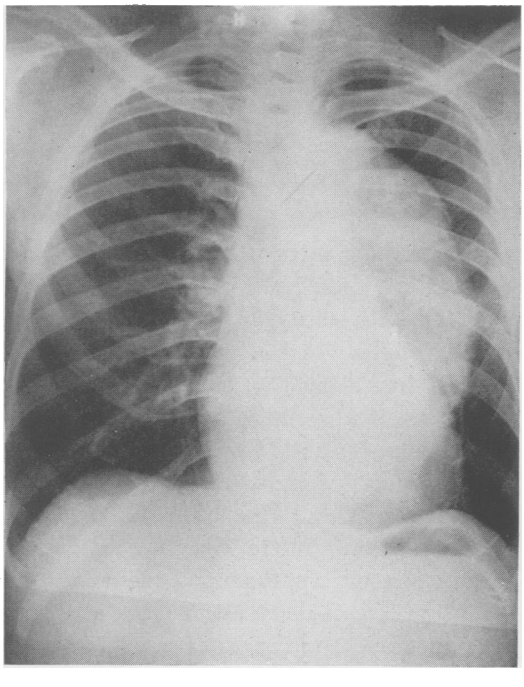

FIG. 11. Roentgenogram of chest in 61-year-old patient with extensive fusiform aneurysm of descending thoracic aorta in which controlled extracorporeal circulation for aortic bypass was used in replacement of entire descending thoracic aorta.

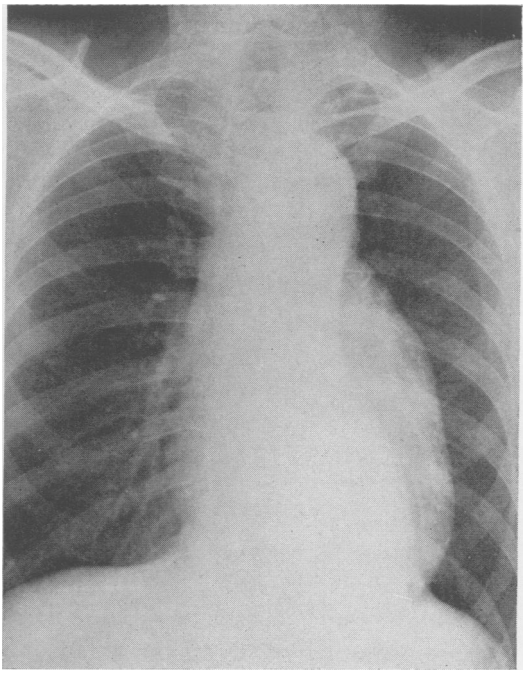

FIG. 12. Roentgenogram of chest in 40-year-old patient with aneurysm of descending thoracic aorta which required total resection and homograft replacement of descending thoracic aorta.

carotid was quickly occluded, the aneurysm was excised, and a 10 centimeter aortic segment was replaced with a synthetic prosthesis. Although the aorta was occluded at this high level for 32 minutes without extracorporeal circulation or other measures to protect the spinal cord, the patient recovered completely from operation without neurologic sequelae.

Acute Dissecting Aneurysms of the Thoracic Aorta: Nine patients with aneurysms of this type were operated upon using previously described methods of aortic repair between one and six weeks after the acute onset of the dissection.[12] The general condition of these patients was usually worse than in any others operated upon for thoracic aneurysms. The average age was 59 years, and most patients were hypertensive with manifestations of cardiovascular, renal, and respiratory disease. Four patients died during the first week after operation, but it may be significant that the last five patients operated upon have all survived. An example of the worthwhile results which may be obtained is found in a 57-year-old man with extensive dissecting aneurysm of the descending thoracic aorta producing severe pain and a left hemothorax, who six weeks after operation was completely relieved of symptoms (Fig. 14). One disturbing feature about this group of patients is the fact that they may have a greater tendency to develop spinal cord damage than patients with simple fusiform aneurysms. This is probably related to the compressive effect of the dissecting process upon segmental spinal vessels. Indeed two patients in this group, both of whom died five days after operation, showed significant neurologic disturbances. It is noteworthy, however, that in both of these cases low rates of flow were employed.

Aneurysms of the Lower Thoracic and Proximal Abdominal Aorta: For aneurysms located in the segment of aorta where the principal vessels to abdominal viscera arise, three patients were operated upon using temporary extracorporeal circulation to perfuse the distal aorta or the renal arteries. One of these patients was apparently recovering satisfactorily when on the seventh postoperative day she developed an acute ruptured dissecting aneurysm of the thoracic aorta requiring emergency operation. Two days following this second procedure she died in heart failure. The other death resulted from the development of a bleeding tendency following resection of an extensive aneurysm producing deep erosion

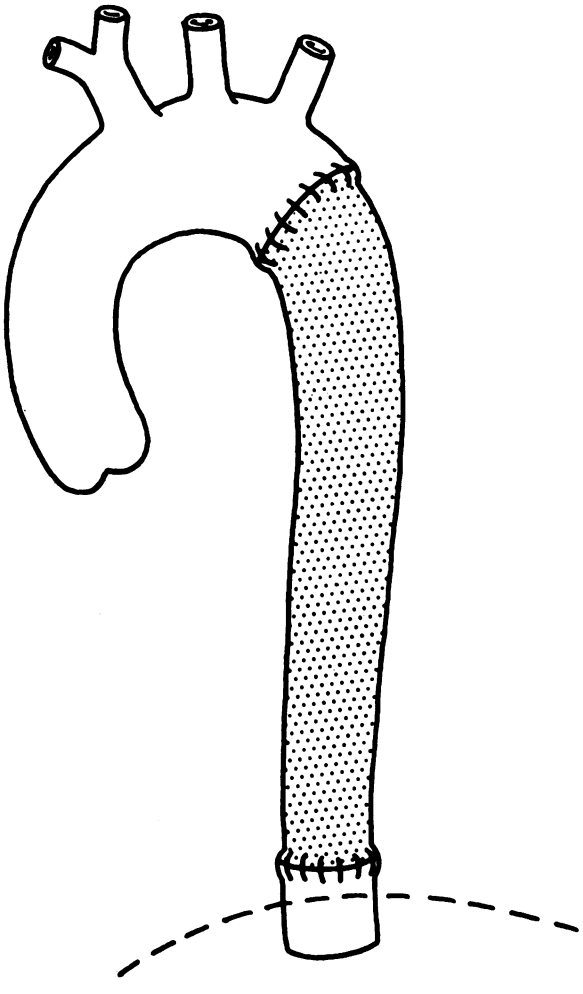

FIG. 13. Drawing showing extent of aortic replacement for aneurysm of descending thoracic aorta used in cases illustrated by Figures 11 and 12 and in two others.

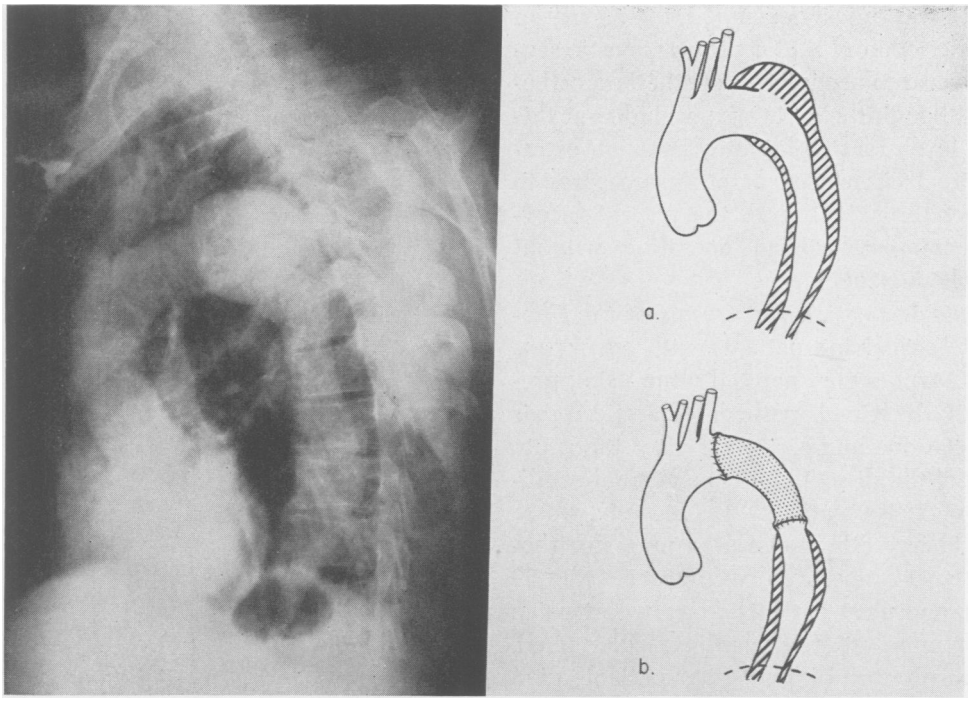

FIG. 14. Angio-aortogram in left anterior oblique position in 57-year-old patient showing acute dissecting aneurysm of descending thoracic aorta and loculated hemothorax in costo-vertebral sulcus. Drawings *a* and *b* show extent of lesion and method of surgical repair used.

of lumbar vertebrae. Although no conclusions can be drawn from this limited experience, the method was found to be technically preferable to others we previously employed and physiologically provided adequate protection against ischemic damage to vital structures. It is interesting to note that in the one surviving patient both the celiac axis and superior mesenteric arteries were occluded by the aneurysm and no effort was made to restore flow through these vessels after grafting the aorta. Apparently adequate collateral circulation to the gastro-intestinal tract in this case was maintained principally through the inferior mesenteric artery.

DISCUSSION

The purpose of controlled extracorporeal circulation in aortic surgery is to provide adequate arterial blood flow to the tissues distal to the point of aortic occlusion and thus to prevent ischemic damage which might otherwise occur during the period of temporary arrest of circulation. Accordingly, a most important consideration is determination of optimum rates of flow for this purpose. In making such determination several criteria may be employed, including particularly the effects of various rates of flow upon the functional integrity of certain highly sensitive organs, such as the central nervous system and the kidneys, to ischemia. Methods for measuring serial functional activity of the central nervous system are not readily available. For this reason and because of the more easily applicable methods of studying renal function as well as because of the large body of experience that has been accumulated in this area both in our hands and that of others, we have relied upon this criterion.

In patients undergoing cardiopulmonary bypass, usually at rates of flow approximately 35 cubic centimeters per kilogram body weight per minute, mean blood pressure in the abdominal aorta during the perfusion was usually 50–60 millimeters of mercury. At these levels of flow and pressure renal function continued at approximately 25 per cent of normal during the perfusion and no permanent reduction in renal function occurred after operation.[2, 18] In those patients undergoing simple aortic bypass in which the flow rate into the abdominal aorta has been 800 to 2000 cubic centimeters per minute the pressure in the distal segment ranged between 28 and 56 millimeters Hg. Studies in these patients indicate that demonstrable renal function disappears below a mean pressure of approximately 32 millimeters Hg. and efforts should be made to provide sufficient volume of flow to keep the pressure above this critical level.[18] In cases in which pressure in the distal aortic segment was maintained above this critical level, renal function continued at ten to 40 per cent of mean normal values during aortic bypass. In patients in whom the rates of flow were sufficient to maintain a substantial pressure in the lower segment, full recovery of renal and neurologic function occurred promptly after operation in most instances. These and other observations lead us to the conclusion that the optimum rate of flow is approximately 20 cubic centimeters per kilogram body weight for aneurysms of the descending thoracic aorta.

In the patient with thoraco-abdominal aneurysms renal perfusion of approximately 75 cubic centimeters per minute was used. This flow was estimated on the basis of renal blood flow studies which indicate that this is an adequate rate to provide measurable renal function during periods of occlusion of the renal arteries. Although this patient died during the early postoperative period of a bleeding transfusion reaction, renal function studies during operation and immediately afterwards revealed satisfactory renal blood flow reflecting adequacy of the perfusion flow rates.

In patients with aneurysms involving the aortic arch perfusion of the carotid arteries has been effective in maintaining cerebral circulation during periods of carotid occlusion and in preserving normal cerebral function after operation. According to Kety[16] normal cerebral blood flow in young adults is 54 cubic centimeters per 100 grams of brain tissue. Under the conditions of lowered blood pressure, however, cerebral vascular resistance is reduced and cerebral oxygen consumption may be only slightly decreased due to a more complete extraction of oxygen from the blood flowing through the brain.[17] Nevertheless, the rate of normal flow was used as a basis for the carotid perfusion. Assuming that the brain weighs approximately 1,250 grams in an adult, a flow of 675 cubic centimeters per minute should be adequate and approximately 350 cubic centimeters per minute should be introduced into each carotid artery. Actually in our patients 500 to 800 cubic centimeters of oxygenated blood were perfused, divided equally between right and left carotid arteries, and it was our conclusion that the higher rates of flow produced the best results.

Although perfusion of the brain, spinal cord, and kidneys may be necessary in operations for some thoracic aneurysms in which controlled extracorporeal circulation is used, perfusion of the coronary vessels is probably unnecessary. Recent studies by Gott *et al.*[15] emphasize the need for retrograde coronary sinus perfusion during periods of interruption of coronary circulation in animals. These authors concluded from their experience with patients in whom retrograde perfusion of the coronary sinus was used in operations involving temporary occlusion of the ascending aorta that this measure was necessary for survival under these circumstances. Our own experience with more than 100 operations where tem-

porary occlusion of the ascending aorta was necessary for periods up to one hour in some instances for treatment of aortic stenosis, aortico-pulmonary septal defect, aortic aneurysms, ventricular septal defects and other lesions indicates that from a practical standpoint attempts at coronary perfusion either forward or retrograde may be unnecessary.[7, 8, 10] Indeed the methods of coronary perfusion are subject to technical failure and if it is not absolutely necessary coronary perfusion should not be employed in such operations. In operations where the aorta is occluded distal to the coronary ostia during operations for aneurysms of the ascending aorta and arch, cardiac function may continue for periods exceeding 60 minutes in some instances. In operations of this type it is probably important to continue periodic insufflation of the lungs during the period of aortic occlusion since coronary circulation depends upon the blood circulating through the heart, lungs, and coronary system. If the coronary ostia must be occluded during aortic resection due to the proximal extent of the aneurysm, complete coronary ischemia is produced and cardiac standstill usually results within a few minutes. Even under these circumstances myocardial viability may be maintained and restoration of normal cardiac activity may be expected upon resumption of coronary circulation.

SUMMARY

Resection of fusiform aneurysms of the thoracic aorta usually requires temporary occlusion of the aorta during the period of aneurysmectomy and graft replacement. Ischemic damage to the brain and spinal cord or left ventricular failure from increased vascular resistance may lead to serious or even fatal consequences unless these factors are controlled.

A series of 32 operations for aortic aneurysm are reported in which methods of controlled extracorporeal circulation were used. For lesions of the ascending aorta and aortic arch total cardiopulmonary bypass with a pump oxygenator was used and carotid perfusion was employed in some cases. For fusiform and acute dissecting aneurysms of the descending thoracic aorta simple aortic bypass without an oxygenator was used to protect the spinal cord from ischemic damage during aortic occlusion.

Observations made in these patients indicate that controlled extracorporeal circulation is a satisfactory method of dealing with problems concerned with excisional therapy of aneurysms of the thoracic aorta. Successful resection and graft replacement of aneurysms located in the ascending aorta, aortic arch, and entire descending thoracic aorta have been possible using such technics.

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Discussion

Dr. Gerbode: I want to again compliment Dr. DeBakey and Dr. Cooley for leading the way in this very exciting and stimulating field, and for showing that from a technical point of view, many of these very distressing lesions can be corrected.

I would like to report on our experiences in treating 4 cases of traumatic aneurysm of the thoracic aorta: all incurred in young people following automobile accidents. All of these aneurysms resulted in a complete tear and separation of the aorta beyond the left subclavian artery, caused by rapid deceleration.

In a preliminary way, before being presented with these cases, we had been interested in finding some other way of overcoming left ventricular strain during cross-clamping of the aorta, and also in preserving the viability of the viscera and spinal cord. My associates, Dr. Braimbridge and Dr. Osborn, and I did some rather extensive experimental studies in this field.

Among the various things we tried, in addition to extracorporeal circulation, was the placing of a 2 mm. catheter in the brachial artery of a dog, and running it into the femoral artery. Even with the low flow which occurs under these circumstances the visceral and nervous systems remain viable after cross-clamping the aorta for 90 minutes. Other experiments with left atrial to femoral artery bypass during 90 minute aortic cross-clamping proved the feasibility of using this technic for aortic aneurysms. This is essentially the same technic used by Dr. DeBakey and Dr. Cooley. I wish to call attention to an important point, that of the necessity of monitoring of the blood pressure in the proximal end. For this, we found that a small needle in the right radial artery, with electro-