Progress in Treatment of Thoracoabdominal and Abdominal Aortic Aneurysms Involving Celiac, Superior Mesenteric, and Renal Arteries

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This is a report of surgical treatment of thoracoabdominal aortic aneurysms and aneurysms of the abdominal aorta from which the visceral vessels arise during the 18 year period from April 5, 1960, to April 20, 1978. The extent of aneurysm is divided into five groups. Group I (10 patients) involved most of the thoracic and abdominal aorta down to celiac axis. Group II (22 patients) involved most of the thoracic and abdominal aorta distal to left subclavian artery. Group III (20 patients) were those with lesser involvement of the thoracic aorta and most of the abdominal aorta. Group IV (18 patients) with involvement of the entire abdominal aorta and Group V (12 patients) with involvement of lower abdominal aorta and renal arteries. Treatment in the majority of these cases was by graft inclusion technique with visceral vessel reattachment by direct suture of orifice to openings made in the graft. Intercostal and/or lumbar arteries were also reattached in some with the more extensive lesions. Aortic and renal artery occlusion times varied from 15 to 155 minutes. Paraplegia developed in five patients with the more extensive lesions but was reduced to one-third and made less severe by reattaching intercostal and lumbar arteries. Renal dysfunction was mild in four patients and severe in three patients after operation. All these were transient except one who died while recovering from renal failure. The latter cases were those difficult to reattach or were not initially successful and required reoperation. Of the 82 patients, 77 (94%) survived operation and long-term follow-up was obtained in 95% of cases, 23 performed over five years ago. Actuarial curves were constructed and compared to survival curves following simple infrarenal abdominal aortic resection. The survival rate both immediately and at six years, were the same.

ANEURYSMAL DISEASE of the aorta rarely involves the segment of abdominal aorta from which the renal, superior mesenteric, and celiac axis arise. When these vessels are involved, the aneurysm may be thoracoabdominal, involving segments of varying length of the descending thoracic aorta and abdominal aorta, or it may be truly abdominal in location, being confined to the aortic segment below the diaphragm involving one or more of these arteries. These aneurysms pose the most difficult challenge to treatment, owing to the difficulties of exposure, the need to minimize the period of visceral organ ischemia required for operation, the technical problem of aortic and arterial reconstruction needed for permanent restoration of circulation, the avoidance of paraplegia, and the control of hemorrhage both during and after operation.

The feasibility of successful therapy in such cases was demonstrated first by Ellis and associates in a patient with lower abdominal aortic aneurysm that involved the origin of the right renal artery.[13] The involved renal artery in this case was successfully reattached in July 1954 using a side arm arterial homograft arising from the aortic homograft. In September 1954, Etheredge and associates successfully replaced a large upper abdominal aortic aneurysm involving the celiac and superior mesenteric arteries using an aortic homograft to which the ends of the celiac axis and superior mesenteric arteries were attached directly.[14] The region of operation was temporarily bypassed during excision and grafting with a polyethylene tube. In October 1955, DeBakey and associates successfully replaced a more extensive aneurysm involving the distal thoracic and upper abdominal aorta including the origins of the celiac axis, superior mesenteric, and renal arteries.[12] Reconstruction in this case was performed using a temporary shunt and consisted of inserting an aortic homograft with appropriate arterial branches which were sutured end-to-end to the involved vessels, after the aneurysm had been excised. Subsequently, DeBakey introduced the technique of permanent dacron aortic bypass with visceral arterial reattachment to appropriately located side arm grafts using smaller dacron tubes in a sequence that limited visceral arterial occlusion time starting with the left renal artery where occlusion times ranged from 10 to 30 minutes.[11]

Presented at the 98th Annual Meeting of the American Surgical Association, Dallas, Texas, April 27, 1978.

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Although the mortality in 42 patients reported in 1965 was 26%, this was the most extensive experience and the best results available; consequently, this procedure became the accepted method of treatment for these extensive lesions.[1,15,20,23,26]

After some experience with this operation, the senior author, attempting to simplify the treatment of these lesions, adopted a new approach in 1965 which combined three technical principles developed by others for application in different situations. These techniques were: 1) graft inclusion without aneurysm resection as advocated by Javid, et al. in the treatment of infrarenal aortic aneurysms, 2) preservation of spinal cord circulation by restoration or maintenance of intercostal and/or lumbar artery circulation as suggested by Spencer in experimental studies in dogs, and 3) reattachment of celiac axis, superior mesenteric, and renal arteries by direct suture of vessel orifice to openings made in the graft, a technique first suggested experimentally by Carrel and Guthrie in 1906 for organ artery reattachment and later in clinical settings by DeBakey, Connolly and others.[3,4,9,16,17,25] A series of 28 patients treated for aneurysms of this type was presented in 1973.[5] Of these 28 patients, 26 (92%) survived. Treatment in the majority was by application of the new approach which was not only simpler, but more easily applied, and associated with fewer complications. The purpose of this report is to update the experience in the treatment of these extensive lesions in 82 patients with emphasis upon operative technique adapted to extent and nature of disease, the presence of associated aortic and arterial lesions, the effects of operation on renal function, and the occurence and prevention of spinal cord dysfunction.

Clinical Material

There were 69 males and 13 females in the series. The ages ranged from 23 to 83 years with the majority being in their 60's and 70's (Fig. 1). The average age of the female was significantly greater than the male and was dependent upon the nature of the aneurysm. The etiology of aneurysm was trauma in one, mycotic (infected arteriosclerotic) in one, syphilis in two, cystic medial necrosis in seven, dissecting in nine, and atherosclerotic in 62 patients. The typical Marfan's syndrome was present in five patients with extensive lesions, three with dissection and two with cystic medial necrosis. The last patients, and those with dissection, and cystic medial necrosis, were in the younger age groups and all except one were males.

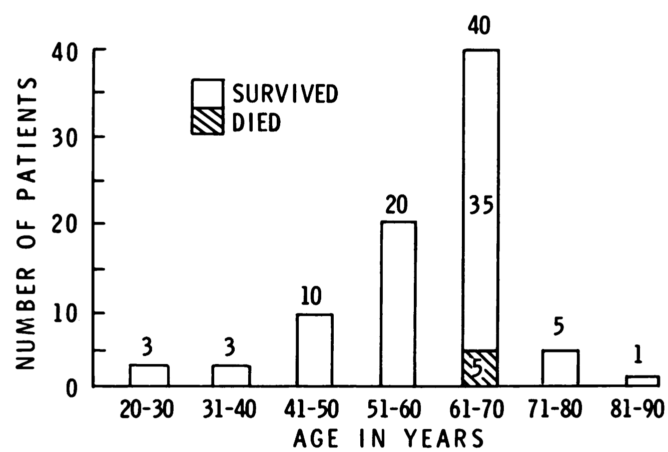


FIG. 1. Survival According to Age (82 patients).

TABLE 1. *Thoracoabdominal and Abdominal Aortic Aneurysms Involving Celiac, Superior Mesenteric, and Renal Arteries*

Group	Involvement	No. Cases	Paraplegia	Survival
I	Thoracic and abdominal aorta without vessels	10	0	10 (100%)
II	Most descending thoracic and abdominal aorta with vessels	22	5 (23%)	20 (91%)
III	Distal thoracic and abdominal aorta with vessels	20	0	18 (90%)
IV	Abdominal aorta with vessels	18	0	17 (94%)
V	Renal only	12	0	12 (100%)
	Total	82	5 (6%)	77 (94%)

Extent of Aneurysm

The extent of aneurysm was variable, dependent upon etiology, and determined the method of therapy. For simplicity in subsequent discussion, the patients are divided into five groups according to extent of disease (Table 1).

In Group I were ten patients in whom the aneurysm was of arteriosclerotic origin, fusiform in nature, and involved most of the descending thoracic aorta and the upper abdominal aorta down to and including the circumference of aorta behind the celiac axis (Fig. 2). In Group II, there were 22 patients who had aneurysms involving all or most all of the descending thoracic and abdominal aorta (Fig. 3). The iliac arteries were involved in five patients and visceral artery origin was involved in all of these cases. In eight of these, the aneurysm was chronic dissection resulting from diffuse dissection occurring from two to six years previously (Figs. 4, 5). An important consideration in therapy was the fact that segments of the descending thoracic aorta starting at the left subclavian artery had been replaced previously at the time of onset. The ascending aorta and aortic valve had also been replaced in two patients (Fig. 4). Dissection in these cases was classical, involving the anterior two thirds of aortic circumference,

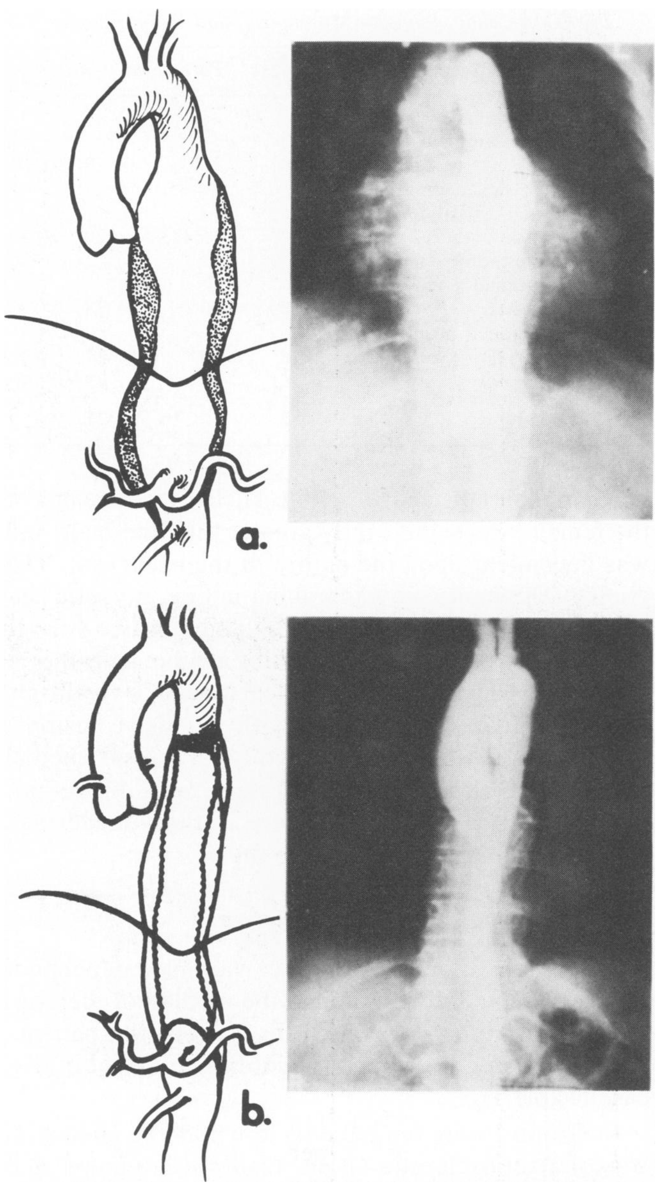


FIG. 2. Illustrations of patients with thoraco-abdominal aortic aneurysm involving descending thoracic aorta and upper abdominal aorta down to the origin of the celiac axis. (a) Diagram and aortogram made before operation showing extent of aneurysm (b) Diagram and aortogram made after operation showing inclusion graft in place and method of replacing aorta behind the celiac axis.

sparing most of the intercostal arteries in the chest, and involving the left lateral half to two-thirds of aortic circumference in the abdomen in seven, and the right lateral two-thirds in one. The left renal artery arose from the false lumen in the former and the right renal artery arose from the false lumen in the latter. The superior mesenteric and celiac axis origins were involved to minor degrees in some. The most significant pathological feature of these cases was the pronounced dilatation of the outer wall of the false lumen which had progressively developed during the years after onset. The aneurysm was of other cause and fusiform in nature in the remaining 14 patients in this group (Fig. 3). Infrarenal aortic aneurysms had been replaced previously in five of the latter patients. In Group III, there were 20 patients in whom the aneurysm was fusiform in nature and involved half or less of the distal descending thoracic aorta and the abdominal aorta, including origins of the visceral arteries (Fig. 6). In Group IV, there were 18 patients in whom the aneurysm was confined to the abdominal aorta and involved the origins of all visceral arteries (Fig. 7). The aneurysm was sacciform in nature and involved only the posterior circumference of aorta behind the origins of the visceral arteries in four of the latter patients. The etiology of these was syphilis in two, atherosclerosis in two, and infected atherosclerosis in one patient. The aneurysm was fusiform in nature and involved the entire circumference in the remaining 14 patients in this group. Extensive fusiform aneurysms of the descending thoracic aorta had been removed previously in four of these patients (Fig. 8). There were 12 patients in Group V in whom the aneurysm was fusiform in nature and involved the lower abdominal aorta including the origin of one or both renal arteries.

Associated lesions of the visceral arteries were common, being present in 16 (22%) of the 71 patients in whom the aortic aneurysm involved the origins of the visceral vessels. Four patients had aneurysms; in two, bilateral aneurysms of the main renal artery, and in one the aneurysm involved the celiac axis, and in the fourth patient, a sacciform aneurysm involved the distal segment of superior mesenteric artery (Fig. 8). Occlusive disease was present in the renal arteries in seven patients, two of whom had had previous nephrectomy (Figs. 6, 15, 18). Similar lesions were present in the celiac axis and superior mesenteric arteries in five patients (Figs. 6, 9, 18).

Clinical Manifestations

Most aneurysms in this series were symptomatic with chest, abdominal, and back pain being the predominant symptoms. Pain was due to pressure on adjacent structures or rupture in most cases. The degree of compression is evident from the frequency of vertebral body erosion occurring in ten patients. In one, erosion had occurred all the way into the neural canal, causing intermittent neural compression and transient neurologic deficits in the lower extremities (Fig. 10). Posterior spinal column stabilization operation using Harrington metal struts was performed two weeks before the aneurysm was resected to avoid injury to the spinal cord during positioning for the latter operation. Moreover, spinal stabilization was re-enforced with bone

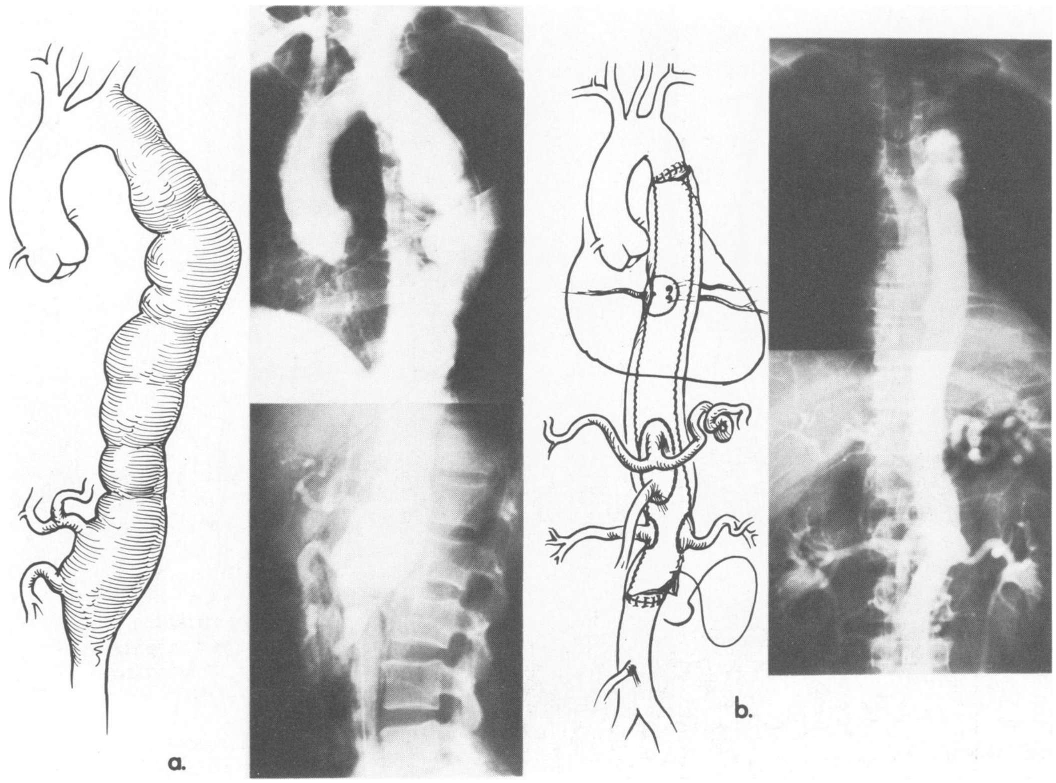


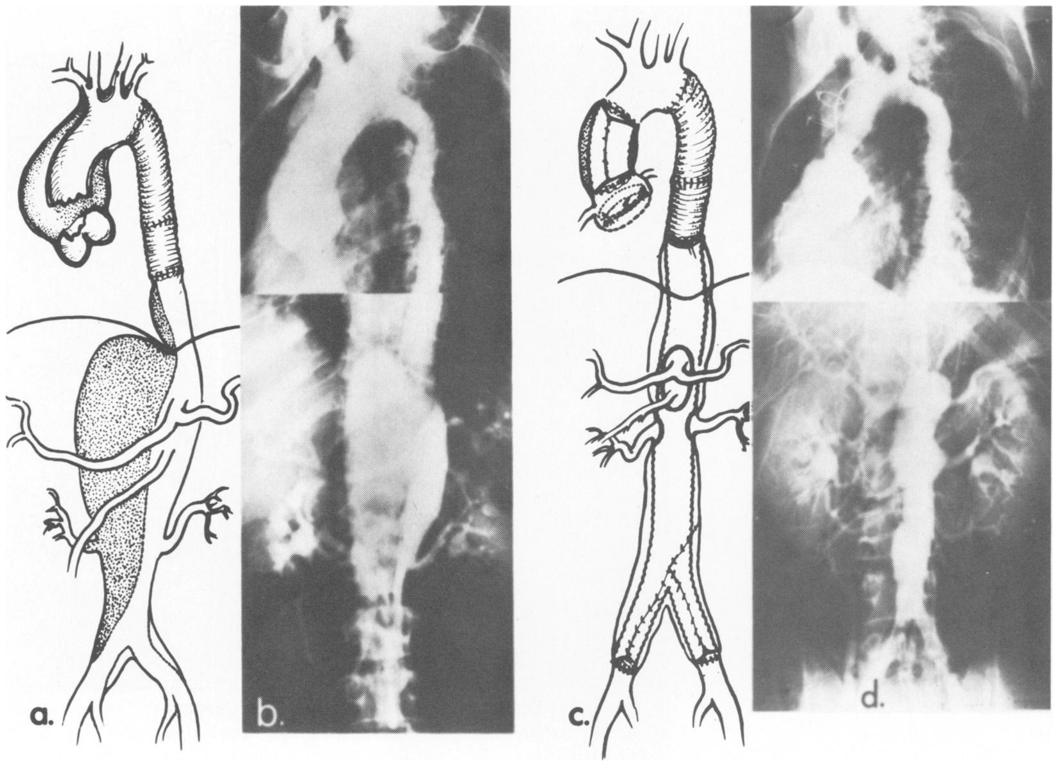
FIG. 3. Illustrations of treatment in patient with extensive thoraco-abdominal aortic aneurysm. (a) Diagram and aortogram made before operation showing location and extent of aneurysm (b) Diagram and aortogram made after operation showing inclusion graft with reattached intercostal and visceral arteries.

graft from the iliac crest to vertebral body at the time of aneurysm operation. The most troublesome erosion pain (back pain) occurred in a patient with an infected arteriosclerotic aneurysm (Fig. 11). This patient had had replacement of infrarenal abdominal aortic aneurysm five years previously with graft removal later because of graft infection. The proximal (infrarenal) and distal iliac segments were closed by suture and leg circulation maintained by axillo-femoral grafts. Suppressive antibiotic therapy was given intermittently to control recurrent infection in the region of aortic operation. Eventually, a large sacciform aneurysm developed in the aortic stump behind the visceral arteries. This aneurysm became infected and caused erosion and osteomyelitis of the adjacent vertebral bodies. The infection was again suppressed and the aneurysm successfully resected. Exposure of the aneurysm required transsection and reanastomosis of the left axillofemoral bypass graft. The patient continues to do well two and one-half months after operaiton on suppressive antibiotic therapy.

Rupture had occurred in 12 patients; into adjacent structures in eight, into the right chest in one, into the peritoneal cavity in two, and into the duodenum in one patient. Associated conditions other than aneurysmal disease were common with some form of heart disease in 20 (25%), hypertension in 15 (18%), chronic fibrotic obstructive pulmonary disease in 18 (22%), peripheral occlusive vascular disease in ten (12%), duodenal ulcer in three, chronic renal failure from nephrosclerosis requiring chronic hemodialysis in one, and one patient had horseshoe kidney with multiple renal arteries (Fig. 12).

Treatment

Treatment varied with the nature, extent, and location of aneurysm and the period of therapy. Early in the experience, modifications of the DeBakey procedure were employed in four patients with extensive involvement of the descending thoracic and abdominal aorta including the segment from which the visceral vessels arose. One of these patients died and operation was complicated by paraplegia in one survivor and in the patient who died. Paraplegia was thought to have been avoided in two by preserving most of the distal abdominal aorta in one and by reattaching lumbar arteries in the other.[5,7] Throughout the study, excision and patch graft repair was considered preferable and employed in four patients in this series who had sacciform aneurysms involving the posterior circumference of abdominal aorta behind the visceral vessels.[5,6] Primary infrarenal abdominal aortic aneurysms in 12 patients (Group V) that also involved the origins of one or both renal arteries were treated by graft inclusion techniques and renal artery reattachment accomplished by one



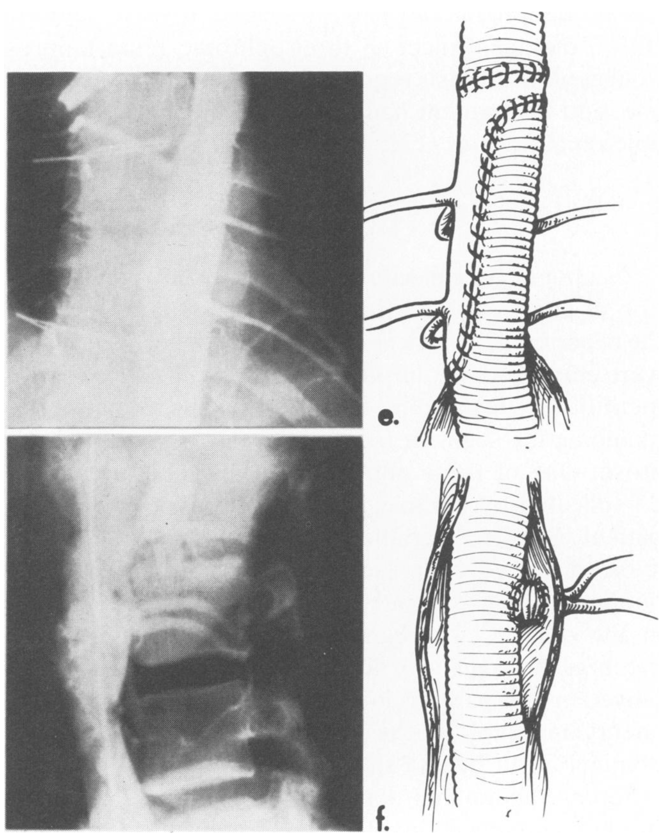


FIG. 4. Illustrations of patient with dissecting aortic aneurysm diffusely involving the thoracic and abdominal aorta who had had two segments of the descending thoracic aorta replaced previously by grafts presenting with aortic insufficiency and painful thoraco-abdominal aortic aneurysm. (a and b) Diagram and aortogram showing extent of residual dissection (c and d) Diagram and aortogram showing aortic valve, ascending aortic graft, and thoraco-abdominal aortic grafts in place with reattached visceral branches. (e) Aortogram and diagram showing method of aneurysmal replacement of segment of thoracic aorta preserving origins of intercostal arteries (f) Aortogram and diagram showing method of preserving lumbar arterial blood flow.

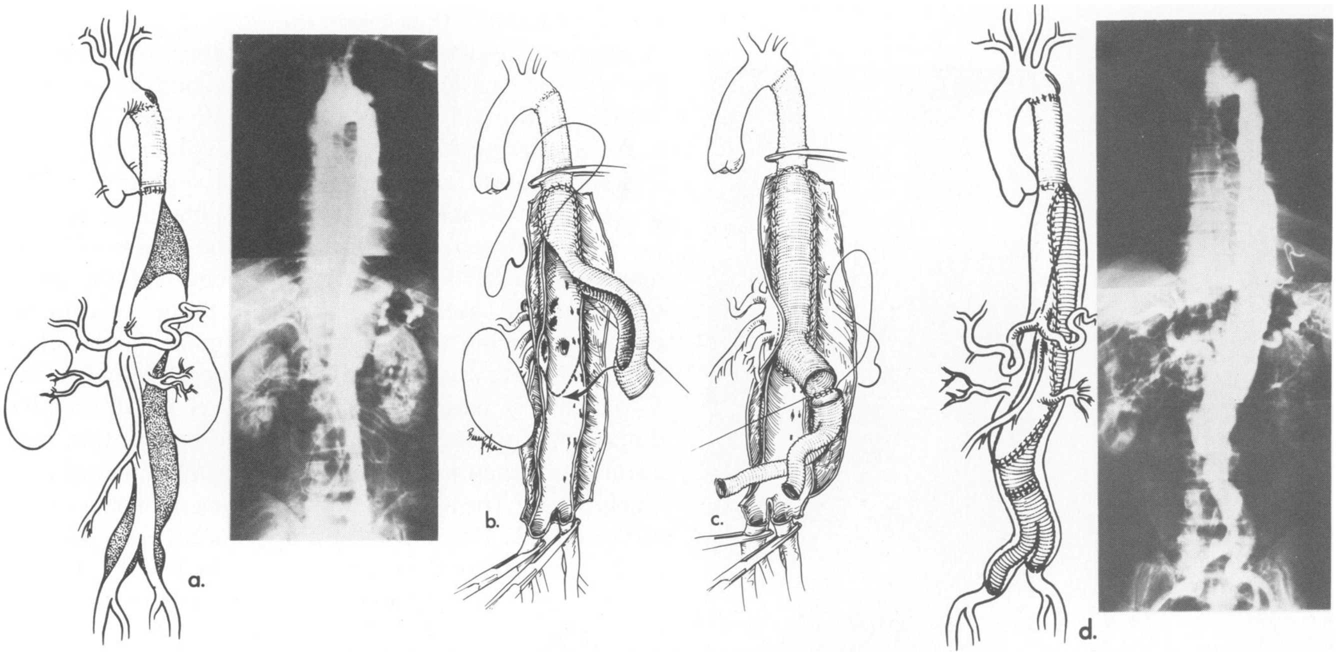


FIG. 5. Illustrations of patient with dissecting aortic aneurysm diffusely involving the descending thoracic and abdominal aorta. The upper descending thoracic aorta had been replaced previously by graft. (a) Diagram and aortogram showing extent of residual aneurysm with left renal artery arising from false lumen (b and c) Method of aneurysmal replacement preserving intercostal and lumbar blood flow and reattaching visceral arteries (d) Diagram and aortogram after operation showing aortic reconstruction.

of three methods, dependent upon the degree of arterial involvement and ease of operation, as previously described.[5] When aneurysmal disease extended out into the renal artery trunk, as it did in three patients, reconstruction was accomplished by insertion of 8 mm knitted Dacron® grafts from the side of aortic graft to the uninvolved distal end of the renal arteries. In nine patients, only the renal artery origin was involved, and

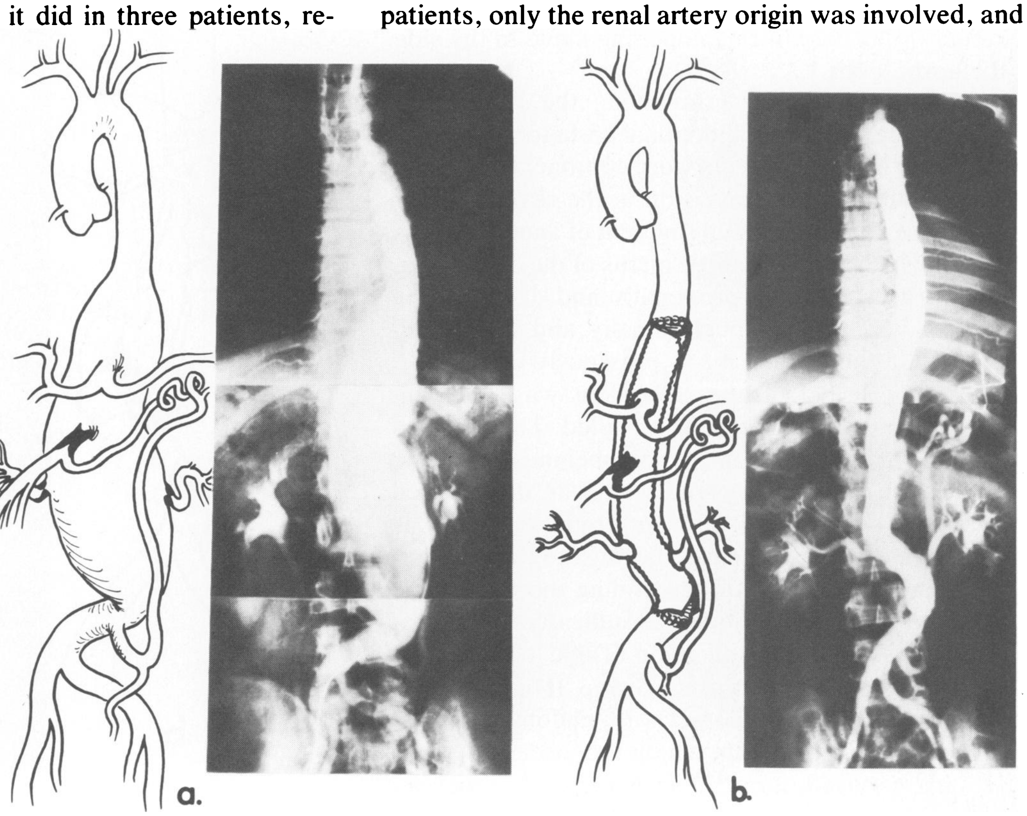


FIG. 6. Illustrations of patient with thoraco-abdominal aortic aneurysm with bilateral renal artery occlusion and complete obstruction of the superior mesenteric artery with good collateral circulation and no gastrointestinal symptoms showing treatment by graft inclusion, endarterectomy of both renal arteries, and preservation of superior mesenteric artery collateral circulation. (a) Diagram and aortogram before operation showing extent of aneurysm and location of occlusion (b) Diagram and aortogram after operation showing inclusion graft and vessel reattachment with patent renal arteries.

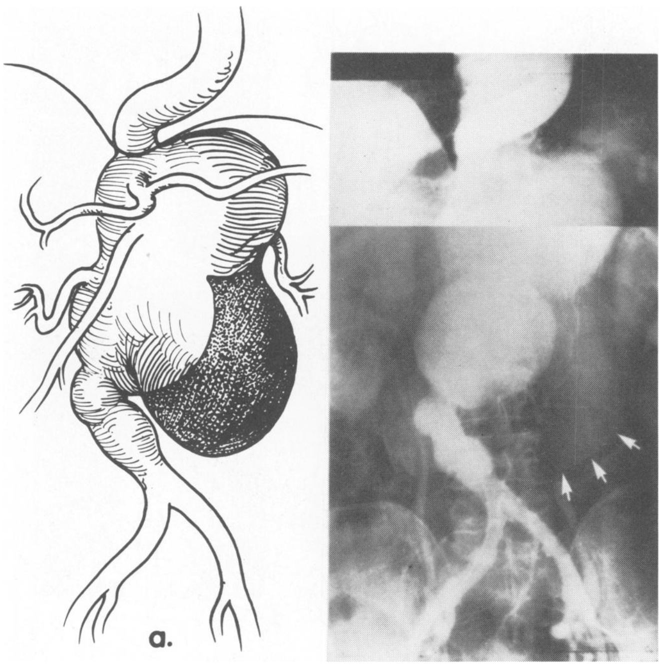


FIG. 7a. Illustrations of patient with large abdominal aortic aneurysm involving origins of the visceral arteries. (a) Diagram and aortogram made before operation showing extent of aneurysm partially filled with clot.

the renal artery was reattached in five of these by button technique, as described by Carrel, and in four patients by direct orifice suture to an opening made in the side of the aortic graft.[3]

Aneurysms in Group I involving the descending thoracic aorta and upper abdominal aorta to the level of the celiac axis in ten patients were approached through a posterolateral thoracic incision in the seventh intercostal space. The abdominal segment of aneurysm was exposed by enlarging the aortic hiatus of the diaphragm. The aorta was clamped proximally and distally. The aneurysm was incised longitudinally and a graft inserted inside the aneurysm, as previously described.[8] When the aorta behind the celiac axis was involved, this was removed and the graft bevelled. The bevelled end of the graft was then sutured behind the celiac axis (Fig. 2). The aneurysmal wall was then closed around the graft. Intercostal artery reattachment was not performed in these cases because extensive experience with treatment of descending thoracic aortic aneurysms by this technique has indicated that paraplegia is a very rare complication (Table 1).[8]

More extensive aneurysms (Group II and III) involving the descending thoracic and abdominal aorta, including the segment from which the visceral vessels arise, are exposed through a thoracoabdominal incision, made in the seventh or eighth intercostal space and extended across the costal arch to the midline of the abdomen and then down the midline to the pubis. Aneurysms involving the abdominal aorta from which the visceral vessels arise (Groups IV and V) are approached through a long midline abdominal incision in the supine position. Aneurysms involving both the abdominal aorta and the most distal segment of the descending thoracic aorta (Group III) may also be approached through an abdominal midline incision which may be desirable in the patient with limited lung function. In such cases, the descending thoracic aorta is exposed through a second incision made in the diaphragm. Aneurysmal exposure and operation in Group V patients is performed anteriorly, as is commonly done for infrarenal aortic aneurysms, except that the aorta is clamped proximally in the aortic hiatus of the diaphragm.[5,7] The abdominal aortic segment of aneurysm in Groups II, III, and IV are approached posteriorly in the retroperitoneal space as described by DeBakey and associates.[11] The peritoneum in the left gutter is incised lateral to the left colon with cautery and extended above to the esophageal hiatus and below to the brim of the pelvis. A relatively avascular plane in the retroperitoneal space adjacent to body wall is entered

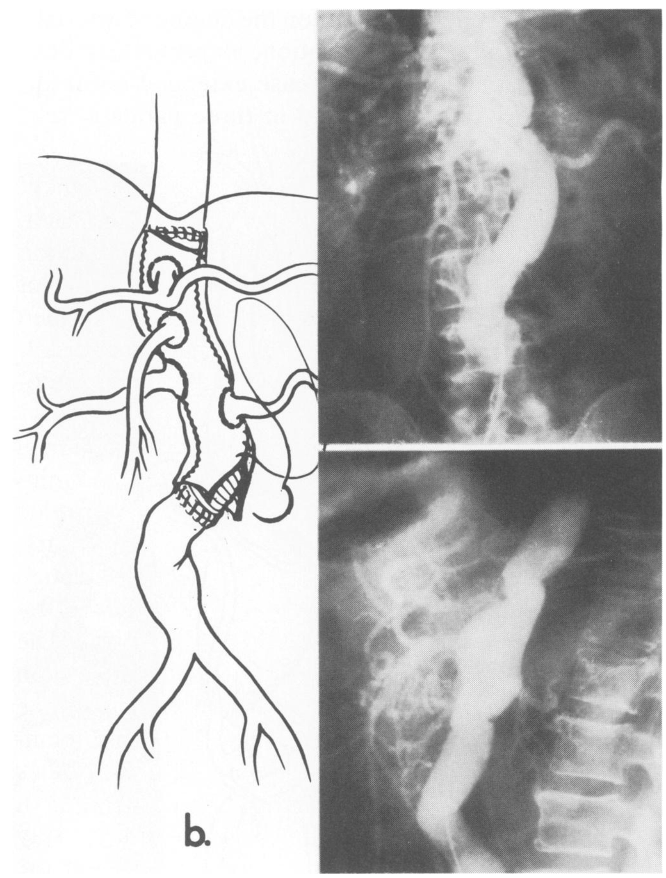


FIG. 7b. Diagram and aortogram made after operating showing inclusion graft and attached visceral vessels.

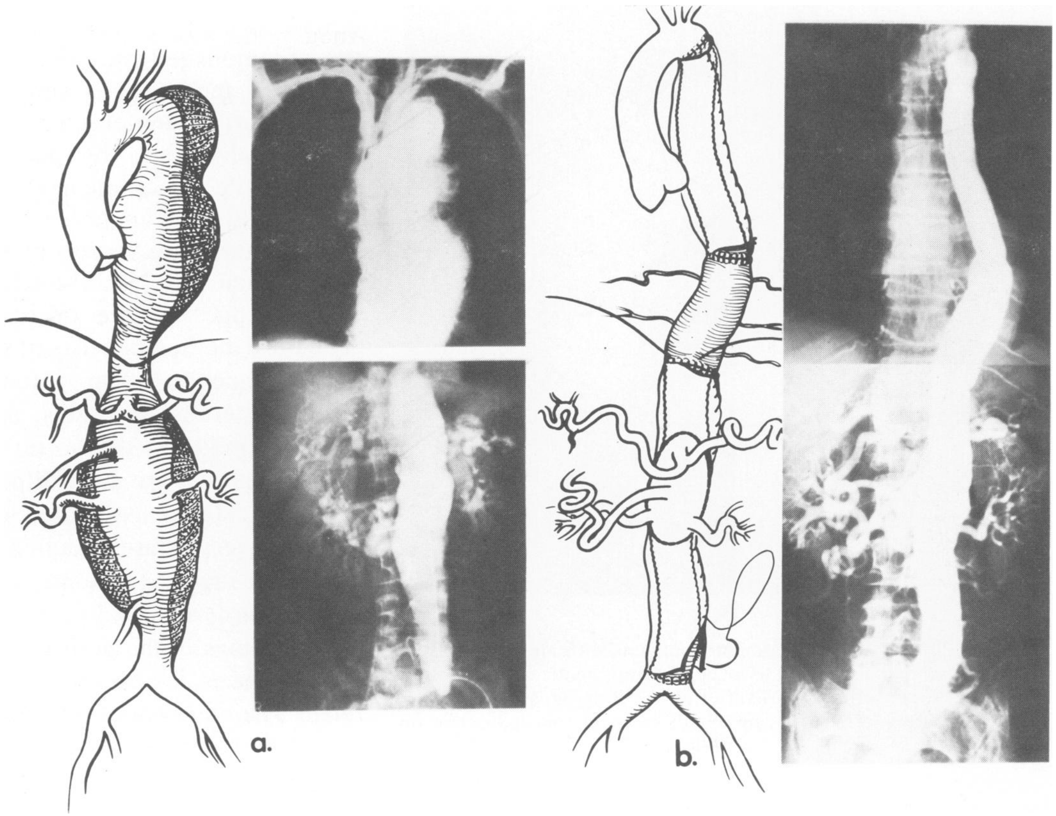


FIG. 8. Illustrations of patient with separate aneurysms of the descending thoracic aorta and the entire abdominal aorta. (a) Diagram and aortogram before operation showing location and extent of aneurysms (b) Diagram and aortogram made after operation done in two stages removing the thoracic aneurysm first showing grafts in place and persistence of intercostal arteries in the intervening normal distal thoracic aorta.

and dissected up to the diaphragm, down to the abdominal aortic bifurcation, and medially to the posterior edge of aneurysm adjacent to the vertebral column. The viscera, including the left colon, left kidney, spleen, body and tail of pancreas, and fundus of stomach, are retracted upward and to the right. Lung retraction for exposure of an aneurysm involving long segments of descending thoracic aorta is more easily accomplished by obstructing the left main stem bronchus and collapsing the lung, using a bifurcation double lumen endotracheal tube.

The proximal uninvolved aorta is exposed by minimal dissection for proximal circulatory control. Uninvolved distal aortic, iliac, or femoral artery segments are similarly exposed. Then, without heparin, shunts, hypothermia, or organ perfusion, circulation through the aorta in the region of operation is controlled by applying clamps proximally and distally (Fig. 13). The aneurysm is incised longitudinally, using cautery on the lateral aspect of the thoracic component of the aneurysm, and posteriorly in the abdominal component in a line adjacent to the lumbar vertebral bodies well behind the origin of the left renal artery (Fig. 13a). Retracing the aneurysmal wall to the right by stay sutures exposes the inside of the aneurysm and the origin of intercostal, lumbar, and visceral arteries and aids retraction of abdominal viscera. Clot is removed but aortic intima is left intact. Bleeding from visceral vessels is controlled with balloon catheters, when necessary, and from the intercostal and lumbar arteries by suture in Groups I, III, IV, and V because paraplegia has not occurred in these cases (Table I). Patients with extensive involvement of both thoracic and abdominal aorta (Group II) may develop paraplegia unless these vessels are reattached. Thus, some or all of these vessels are spared for reattachment. Both the manner by which cord circulation is restored and reconstruction by graft is accomplished in such cases depends on whether the aneurysm is due to dissection or is simply fusiform in nature and is described accordingly.

Extensive Fusiform Aneurysms (Group II)

A pair of intercostal and/or a pair of lumbar arteries are spared, to be reattached later to the graft, bleeding is controlled by balloon catheters, suture tourniquet, or clamps. A transverse incision is then made in the anterior half of aortic circumference at the proximal and distal ends of the previously made longitudinal incision (Fig. 13a). A woven, straight dacron tube of appropriate size is attached within the aneurysm end-to-end proximally to the uninvolved aortic segment (Fig. 13b). Traction is placed on the graft and an oval

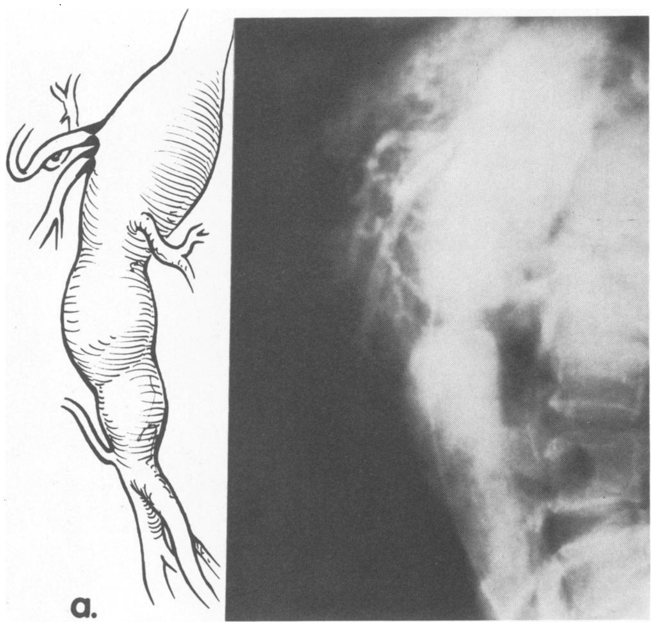
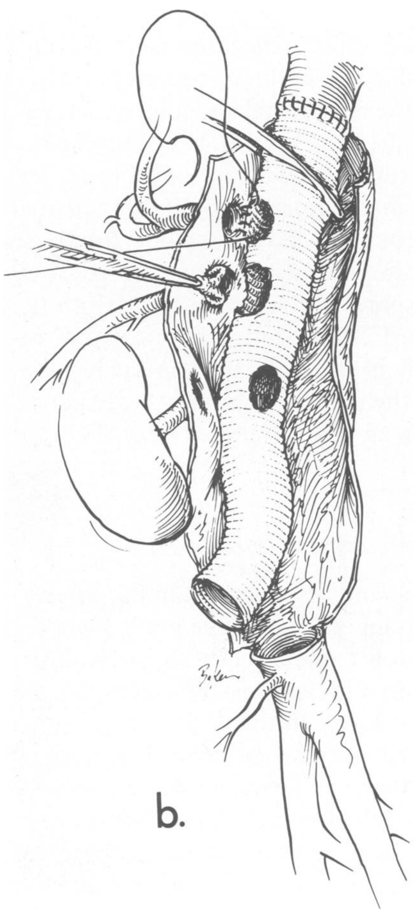


FIG. 9a. Illustrations of treatment in patient with aneurysm of the entire abdominal aorta with associated symptomatic obstruction of ceilac and superior mesenteric arteries. (a) Diagram and aortogram made before operation showing extent of aneurysm and occlusion (in black).

opening is made in the graft, opposite the intercostal arteries which are to be reattached. Reattachment may be accomplished by either of three techniques. The preferred technique is simply to suture the opening of the graft circumferentially around the orifices of the intercostal vessels by placing the sutures directly through the intact aneurysmal wall (Figs. 3, 13c and 18). A button of aneurysm wall containing the origins of the intercostal vessels may be dissected out of the aneurysmal wall, and the edges of the button sutured to the edges of the opening made in the graft.[17] The third method consists of suturing one end of a very short segment of 10 mm Dacron tube around the origin of the intercostal vessels, and the other end to the opening made in the aortic graft (Fig. 4f). The last two techniques are more difficult, require more time to perform, and are associated with more blood loss. The visceral vessels are attached next in sequence; celiac axis first, superior mesenteric artery second, right renal artery third, and finally, the left renal artery by suturing openings in the graft circumferentially around the vessel origins, incorporating full thickness of aneurysmal wall. The numbers of attachments varies with the distance between vessel origins. In some patients, one



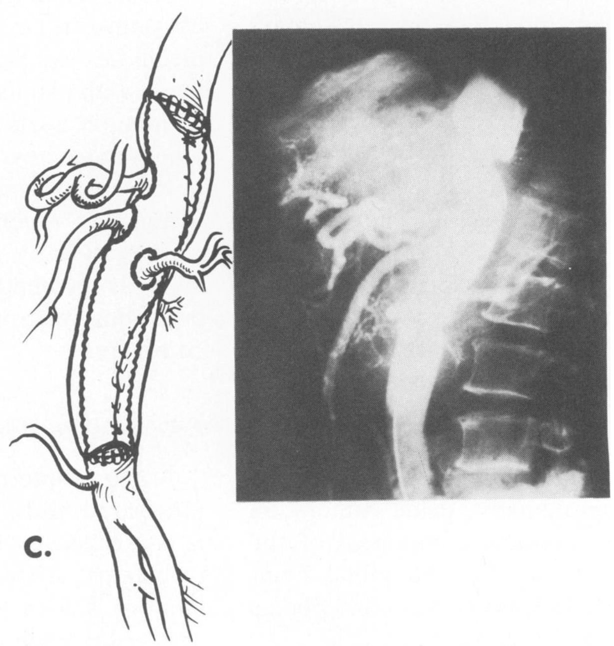
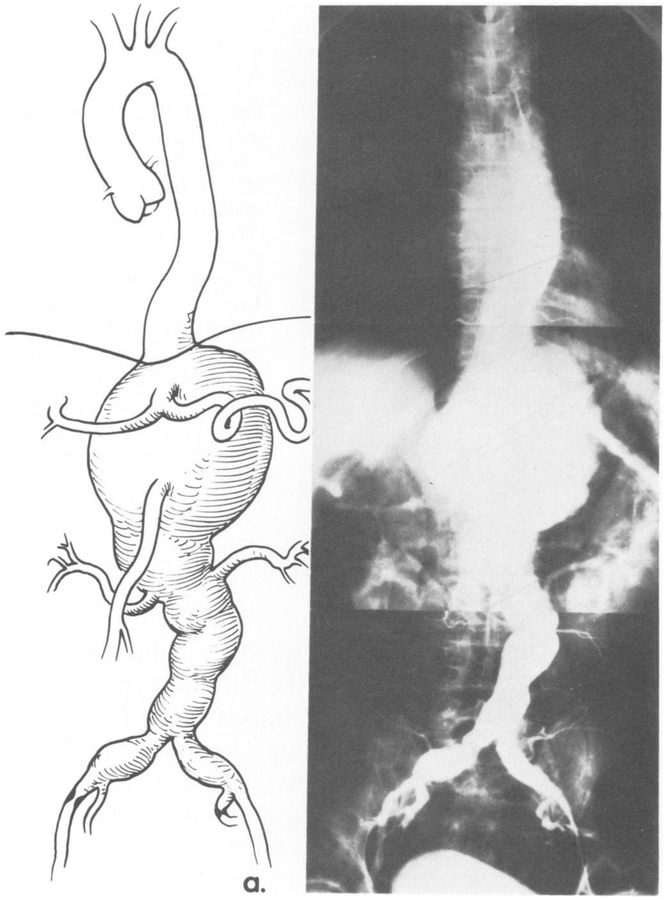


FIG. 9b. Diagram showing method of graft insertion, vessel reattachment, and endarterectomy from inside aneurysm.

FIG. 9c. Diagram and aortogram made after operation showing graft in place and patent vessels.



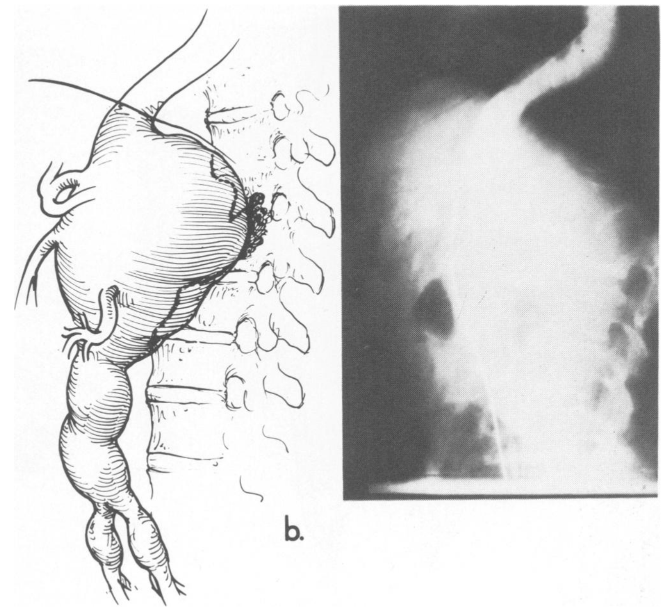
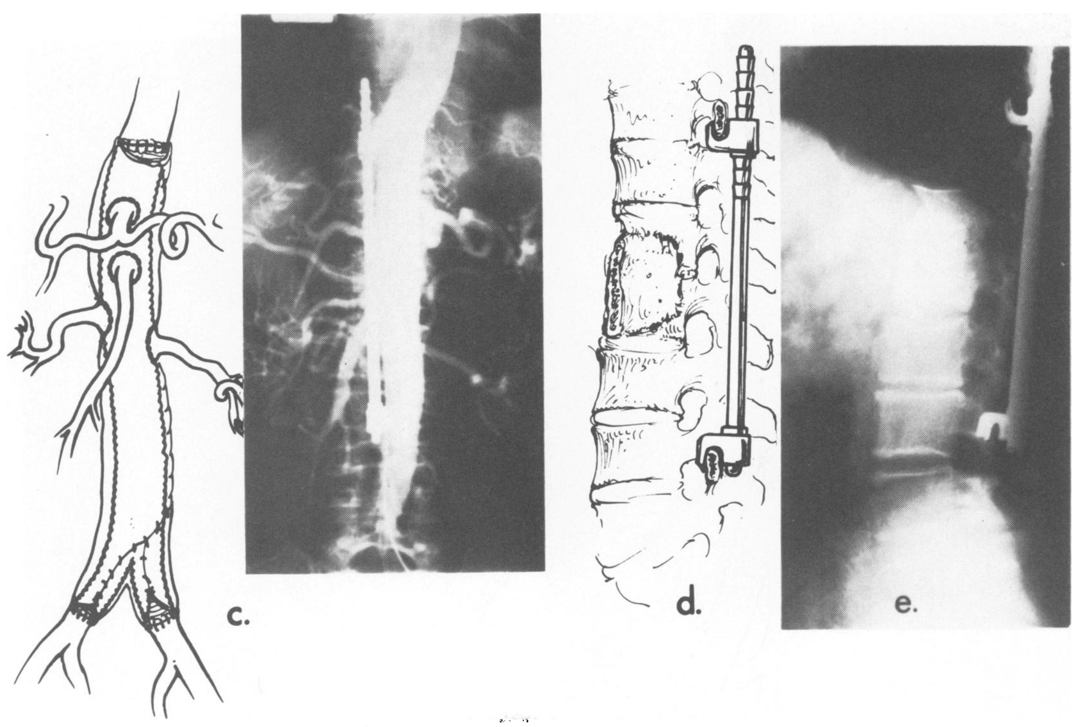


FIG. 10. Illustrations of patient with aneurysmal disease of the entire abdominal aorta with erosion into the neural canal treated by insertion of Harrington struts posteriorly to the spine and then replacing the aneurysm and bone grafting of eroded vertebral body. (10a) Diagram and aortogram before operation showing extent of aneurysm.

FIG. 10b. Diagram and lateral aortogram before operation showing extent of spinal erosion.

FIG. 10c. Diagram and aortogram made after operation showing inclusion graft and metal struts in place (10 d–e). Diagram and roentgenogram made 2½ years after operation showing location and status of bone graft.



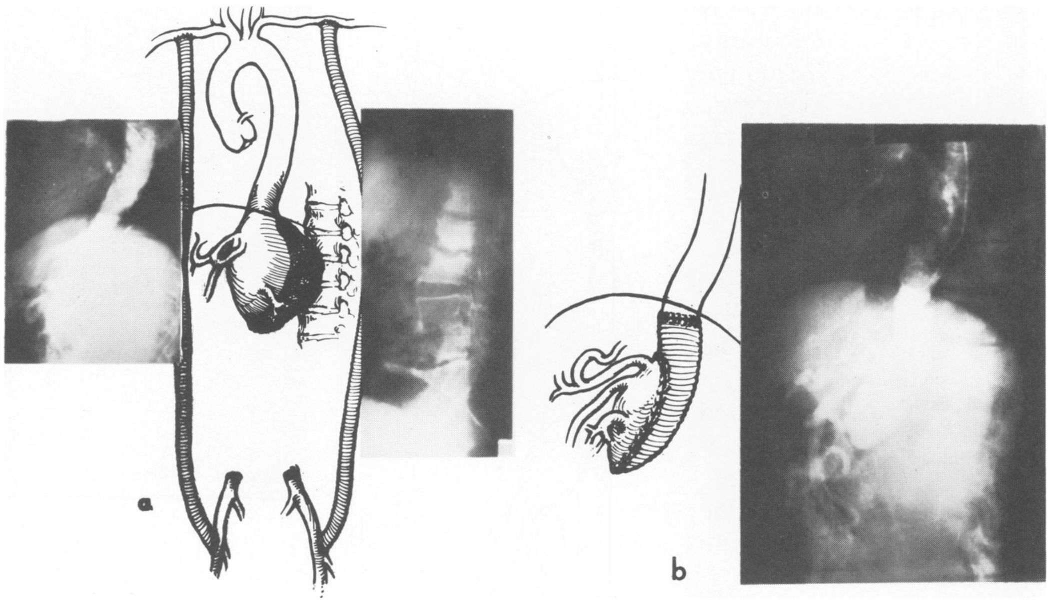


FIG. 11. Illustrations of treatment aneurysm occurring in distal aortic stump after removal of infected graft used to replace abdominal aortic aneurysm five years previously. (a) Diagram, aortogram, and spinal roentgenogram showing location and extent of aneurysm with osteomyelitis and erosion of vertebral body. (b) Diagram and aortogram made after operation showing graft in place.

or more origins may be close together and may be reattached together to one opening in the graft (Fig. 14). In other cases, the origins are relatively widely separated and preferably inserted separately (Figs. 9 and 13b). In any case, left renal artery attachment is made on the lateral aspect of the graft to void kinking and obstruction upon return of viscera into the abdominal cavity. This is conveniently accomplished by twisting the graft to the right after attaching the other vessels, and before making the final opening into the aortic graft. After completing the left renal artery reattachment, the aorta is flushed by temporarily removing the proximal clamp; the balloon catheters are then removed, the graft is clamped distal to the left renal artery and proximal clamp removed, restoring circulation to intercostal and visceral arteries. The distal end of the graft is then sutured end-to-end to uninvolved distal aorta or to a bifurcation aortic graft. In the latter cases, the ends of the iliac limbs are sutured to the ends of common iliac arteries, or to the sides of the external iliac or common femoral arteries, depending upon distal involvement either by aneurysm or

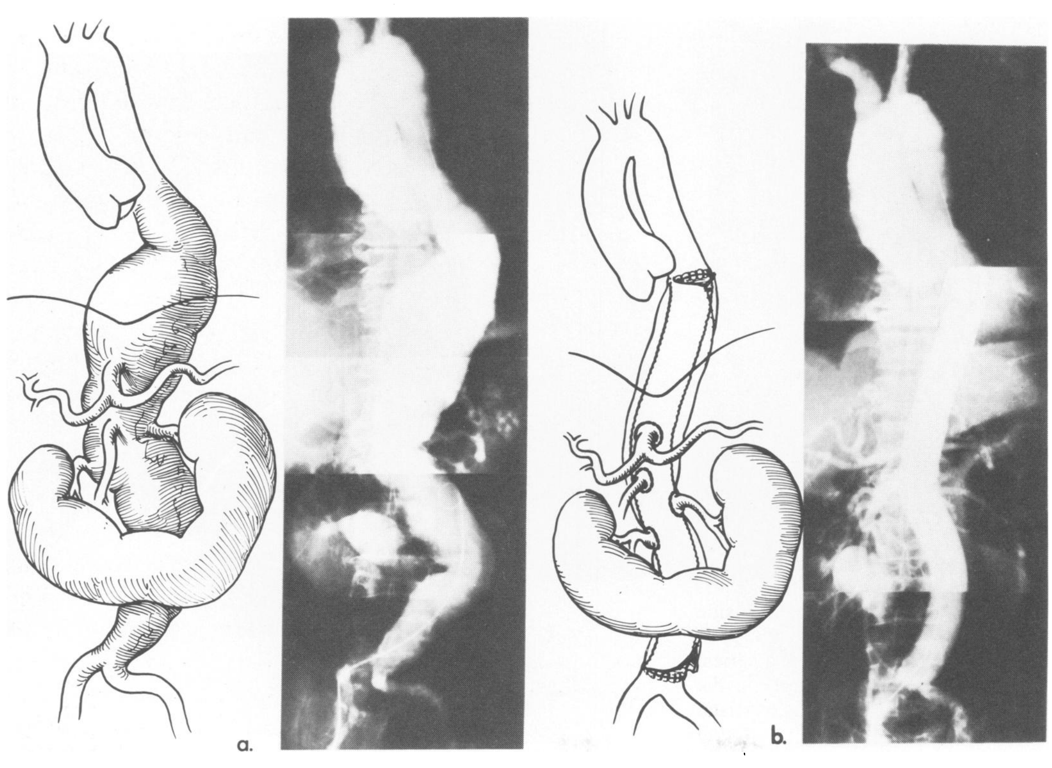


FIG. 12. Illustrations of patient with thoraco-abdominal aortic aneurysm which had ruptured into right chest complicated by presence of horseshoe kidney. (a) Diagram and aortogram before operation showing extent of aneurysm and location of horseshoe kidney, (b) Diagram and aortogram after operation showing aortic reconstruction by graft inclusion and visceral artery reattachment to graft.

associated occlusive disease. The aneurysmal wall is then sutured around the graft; due to disparity of diameter, the aneurysmal wall is embricated in appropriate fashion (Fig. 13c). The viscera are returned to the abdomen and operation completed by closing the wounds.

Dissecting Aneurysms (Group II)

The unique qualities of applying the graft inclusion technique to chronic dissecting aortic aneurysms lies in managing the pathology of dissection itself, and the method of vessel reattachment. In regard to the first quality, the outer wall of the false lumen is entered as previously described, care being taken to avoid injury to the renal artery arising from the false lumen. The inner wall of the false lumen which is also the damaged wall of the true lumen is identified and incised longitudinally. Both of these structures are retracted, exposing the normal or undissected aortic circumference from which the intercostal and visceral vessels arise (Fig. 5). The above inner wall of false lumen is excised laterally and medially to normal aorta. A part of the circumference of a tubular, woven dacron

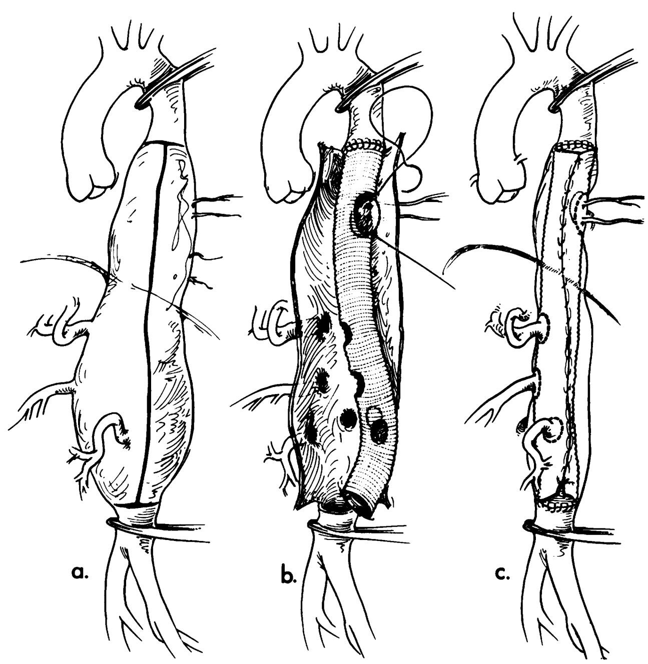


FIG. 13. Diagrams showing graft inclusion and direct vessel reattachment technique as employed in treatment of extensive aneurysm involving descending thoracic and abdominal aorta in which visceral vessel origins are widely separated. (a) The aorta is clamped proximal and distal to aneurysm. The aneurysm is incised longitudinally and transverse incisions made at each end through the anterior half of aortic circumference. (b) Graft is inserted inside aneurysm end to end anastomosis, and opening made in the graft and sutured circumferentially around origins of intercostal arteries. Under appropriate tension openings are sequentially made in the graft and sutured around the visceral artery origins. (c) The distal anastomosis is completed and the aneurysmal wall is sutured around the graft.

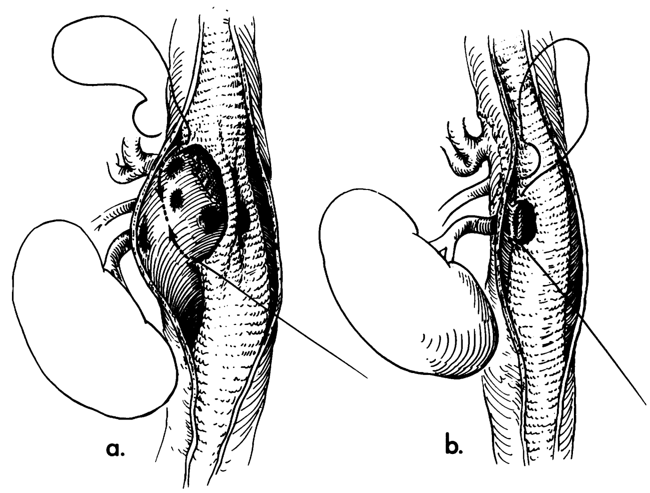


FIG. 14. Diagram showing variation in technique of visceral artery reattachment when two or more vessels arise close together. (a) Origins of celiac axis, superior mesenteric, and right renal arteries are attached to a single opening in the graft. (b) Attachment is completed by reattaching left renal artery orifice to separate opening.

graft is removed equal to the dissected circumference of aorta. This portion of the graft is sutured in place as a patch, restoring a more normal aortic circumference and preserving the origins of the intercostal, lumbar, and visceral arteries. Reconstruction distal to the renal arteries is accomplished by insertion of tubular graft, usually with a bifurcation graft, the distal ends of which are attached either to the external iliac or common femoral arteries. An alternative to this technique, especially when there is excessive back bleeding from the intercostal, lumbar, and visceral vessels, is reattachment of the visceral vessels and a part of the thoracic aorta by this technique (Fig. 4). Lumbar arteries may be reattached in such cases when desired by techniques previously described (Fig. 4f).

Less extensive aneurysms, Groups I, III, IV, and V, are treated similarly regarding graft inclusion and vessel reattachment when appropriate, except that intercostal and lumbar artery circulation reattachment is not required in these cases, since paraplegia has not been observed whether or not reattachment has been performed (Table 1). Exposure in these cases differs according to location and extent as described above (Figs. 7–11).

Treatment of Associated Lesions

Occlusive lesions of the celiac, superior mesenteric, and renal arteries arising at and limited to the origins of the involved artery were treated by endarterectomy from inside the opened aortic aneurysm (Fig. 9).[7] A circular incision was made around the involved vessel orifice in the diseased aortic intima. The cleavage plane between the diseased inner layer and the normal outer layer of aortic wall was entered and dissected cir-

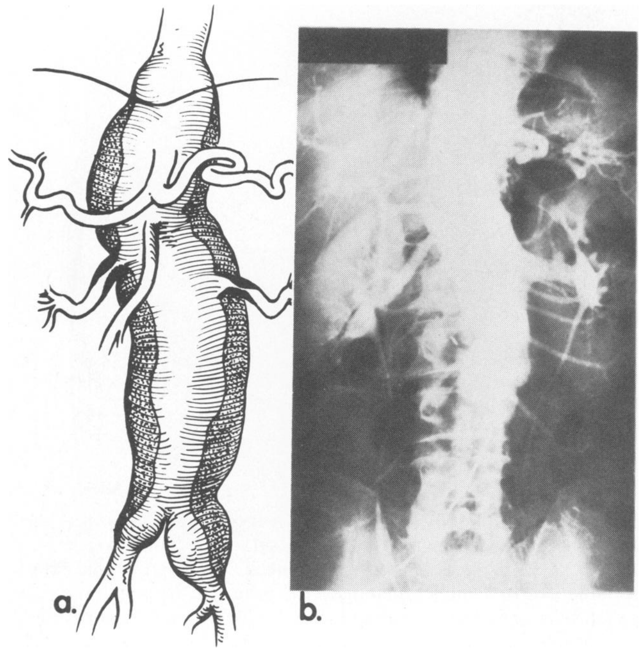


FIG. 15. Illustrations of patient with leaking abdominal aortic aneurysm involving all vessels with associated occlusion of both renal arteries treated by graft inclusion and vessel reattachment. Renal endarterectomy was unsuccessful and case illustrates method of restoring circulation at second operation. (a-b) Diagram and aortogram made before operation showing extent of involvement by aneurysm and occlusive disease.

cumferentially to vessel origin. The plane of dissection was then continued distally into the involved vessel until the obstructing atheroma could be removed. Any distal intimal "flaps" were removed to prevent recurrent obstruction. More extensive and distal lesions or unsuccessfully treated reattached arteries were treated by graft bypass (Figs. 15, 18). Such lesions occurring in the left renal artery later proved to be preferably treated by removing the spleen and suturing the end of the proximal splenic artery to the side or end of the distal uninvolved renal artery (Fig. 16). Aneurysms of the visceral arteries were excised and replaced by grafts.

All renal artery lesions were treated to prevent aneurysmal rupture and to treat the associated hypertension. All symptomatic occlusive lesions of the celiac and superior mesenteric arteries were treated to relieve symptoms and to prevent progression to ischemic necrosis of bowel. Similarly, asymptomatic partial occlusions of the latter vessels were treated to prevent progression of occlusion. Asymptomatic completely obstructing single vessel occlusions of the latter vessels were not treated; however, meticulous care was exercised to preserve the collateral routes of circulation (Fig. 6).

Results

Of the 82 patients in this series, 77 (94%) patients survived (Table 1). Death occurred in the patients with the most extensive aneurysms and was due to multiple system disorders in two and from hemorrhage in three. Hemorrhage in the latter patients was due to coagulation defects occurring toward the end of operation due

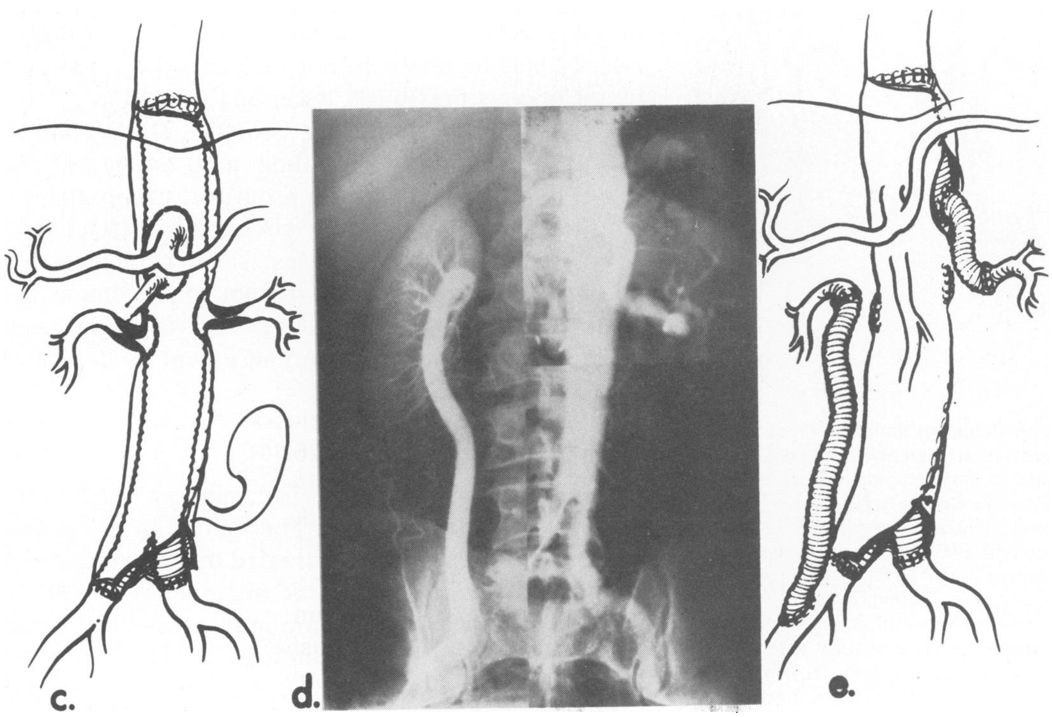


FIG. 15c. Diagram of aortogram made immediately after operation while patient was anuric showing occlusion of both renal arteries. (d-e) Aortogram and diagram made six weeks after operation showing graft method of restoring renal circulation after initial failure with transaortic endarterectomy and vessel reattachment.

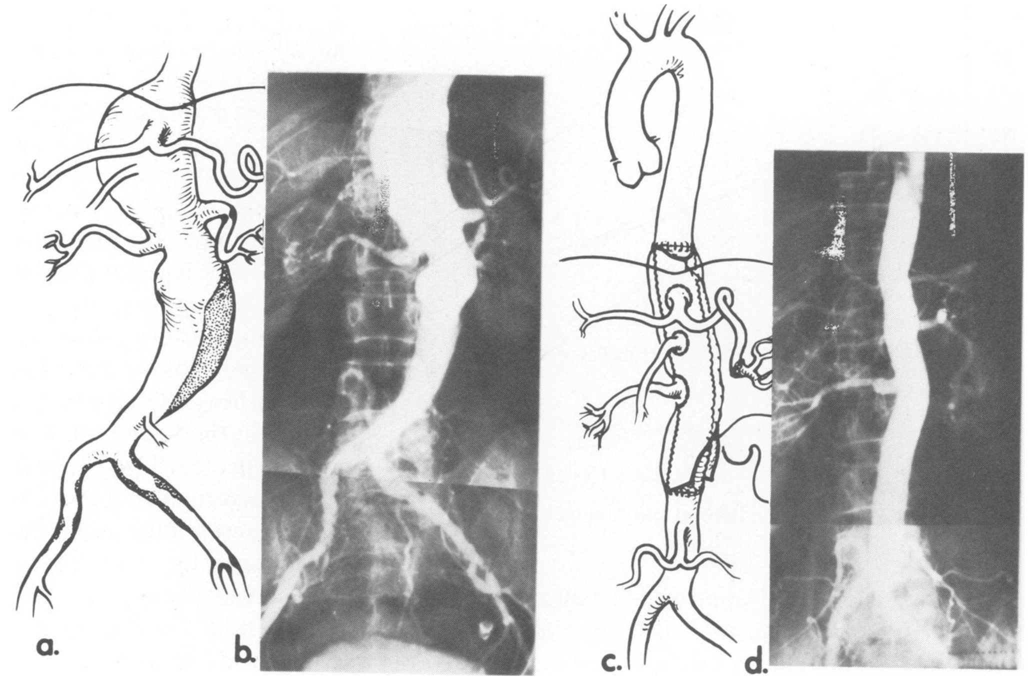


FIG. 16a–d. Illustrations of patient with aneurysm of the abdominal aorta involving all visceral vessels with distal stenosis of left renal artery in whom reconstruction was performed by inclusion and vessel reattachment technique except left renal artery was reconstructed by using splenic artery. (a-b) Diagram and aortogram before operation showing extent and location of disease. (c-d) Diagram and aortogram after operation showing inclusion graft in place with attached celiac axis, superior mesenteric, and renal arteries.

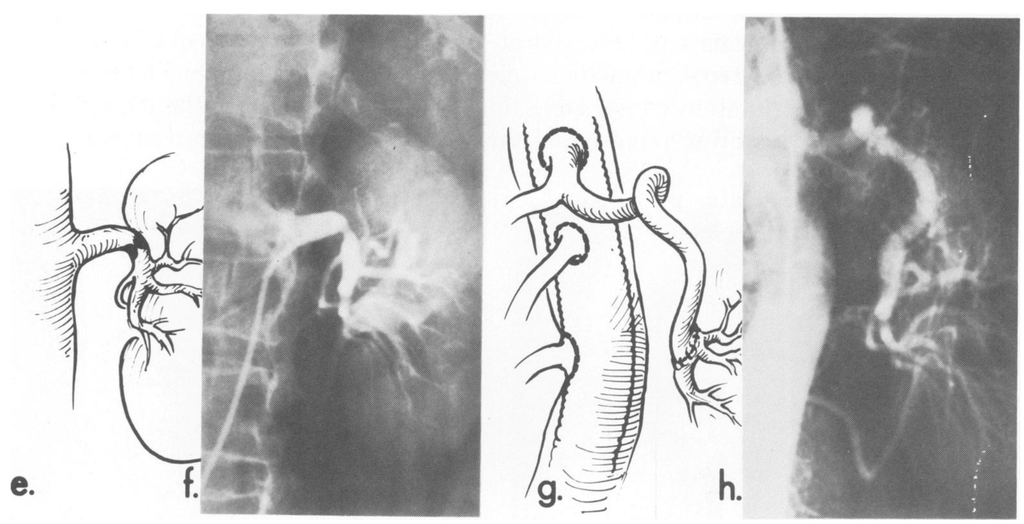


FIG. 16e–h. Diagrams and arteriograms showing location of lesion and reconstruction of left renal artery using splenic artery.

to lack of understanding in the use of blood element method of transfusion. In this regard, it is significant that death or major complication has not occurred in the last 22 patients submitted to operation. Despite not using heparin, embolization and distal thrombosis were not a problem. Balloon catheters were successfully used in one case to clear the iliac and femoral arteries of thrombi. No amputations were required and pre-existing distal occlusive lesions in the legs were not worsened by operation. There were no ischemic disturbances of the gastrointestinal tract. The two principal areas of complications were renal and spinal cord function, as discussed below.

Renal Artery Occlusion and Renal Function

Renal circulation in these cases was interrupted by aortic and renal artery occlusion for periods ranging from 15 to 150 minutes (Table 2). The longer periods of occlusion were in patients in whom arterial reconstruction was difficult or failed and had to be repeated at a second operation done immediately after the first (Fig. 15). Attempts were made to adequately hydrate the patients before operation, and 25 g Mannitol were given before aortic occlusion. Blood volume was monitored by central venous pressure and a Swan-Ganz catheter (in the recent cases) and maintained by

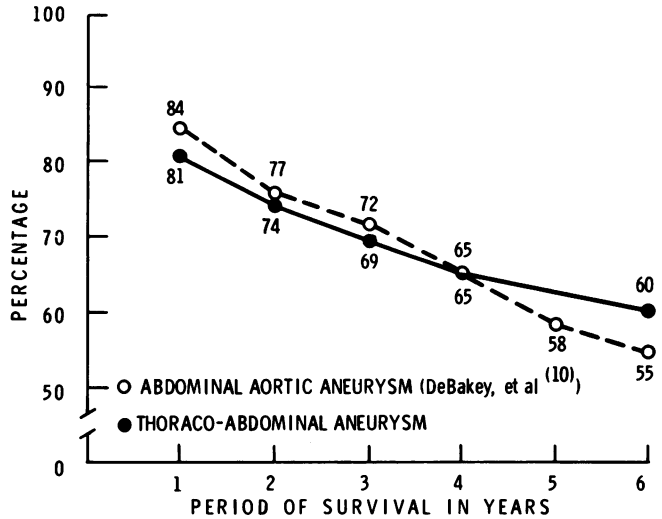


FIG. 17. Survival: Thoraco-Abdominal and Abdominal Aortic Aneurysms.

blood transfusions and appropriate colloid and electrolyte solutions during and after operation. Indigo carmine clearance time was determined in the most recent 34 patients by injecting 5cc indigo carmine intravenously at the time renal circulation was re-established (Table 3). Urine excretion stopped in all cases during the period of renal ischemia and resumed at varying intervals after restoring renal circulation, depending upon such factors as duration of ischemic time, success of operation in restoring renal blood flow, adequacy of blood volume, and variables not recognized. The gross indigo carmine appearance time was variable but on the average was about equal to the period of ischemia (Table 3). In the treatment of other vascular problems involving renal artery occlusion, our experience suggests that if indigo carmine is excreted, renal circulation has been adequately restored; however, this finding does not insure against the development of acute tubular necrosis. In earlier experience, four patients had not excreted urine by the end of operation. Aortography after wound closure demonstrated main renal artery obstruction in two patients, and severe spasm of the distal branches of the renal arteries in the others. Renal artery reconstruction was reperformed in the former and the latter were treated medically (Fig. 15). Two of these patients developed acute tubular necrosis and required dialysis (Table 2).

Blood creatinine and urea nitrogen were determined before operation and daily after operation. Any elevation of creatinine was considered evidence of renal dysfunction. On this basis, seven (9%) of 78 patients leaving the operating room and not already on chronic hemodialysis showed signs of renal dysfunction (Table 2). This finding was transient and lasted from seven to 14 days in four. Hemodialysis was required in three patients, two of whom survived. The other patient died from multiple causes although renal function was improving. On the basis of the above criteria, renal dysfunction occurred regardless of the period of renal

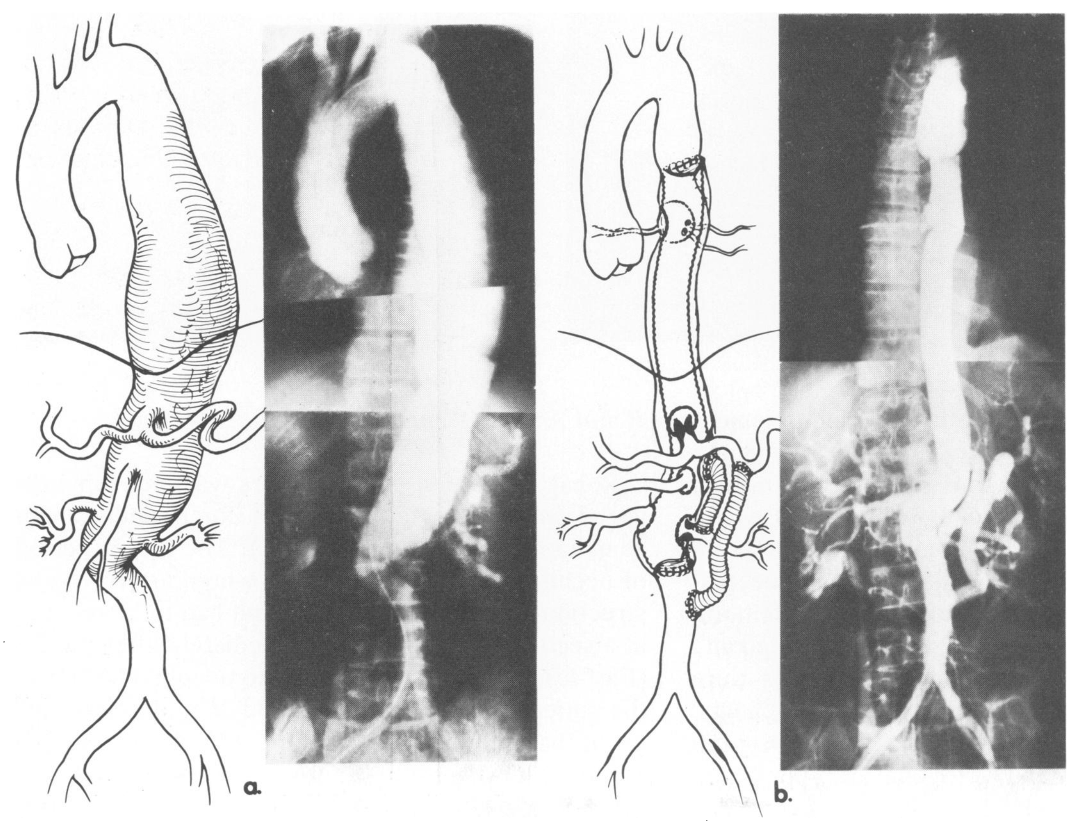


FIG. 18a,b. Illustrations of patient with extensive thoraco-abdominal aortic aneurysm involving most of the descending thoracic aorta and the abdominal aorta showing method of reconstruction. (a) Diagram and aortogram before operation showing extent of disease. (b) Diagram and aortogram made after operation showing method of reconstruction including intercostal reattachment and reattachment of superior mesenteric and right renal artery by direct suture and celiac axis and left renal artery reconstruction by graft due to associated occlusive disease.

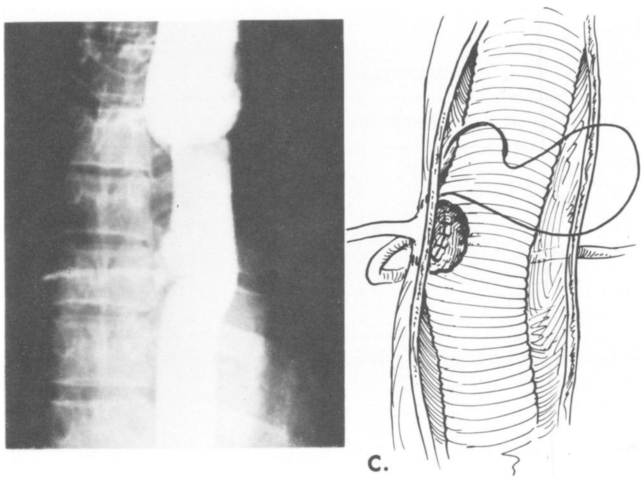


FIG. 18c. Aortogram and diagram showing method of intercostal artery reattachment.

ischemia; however, the greatest incidence of severe dysfunction occurred with periods of occlusion up to two and one-half hours in the patients in whom renal artery reconstruction was difficult or had not been accomplished by first operation.

Cord Ischemia

Cord ischemia manifested by neurological deficits of the lower body occurred in five (6%) of the 82 patients (Table 5). It is significant that this complication occurred only in patients with Group II lesions with extensive involvement of both the descending thoracic and abdominal aorta (Table 1). Paraplegia was mild in two, moderate in one, and severe in two patients. Both patients with severe manifestations died of other causes. One died from myocardial infarction and paraplegia, in this patient, occurred 18 hours after operation at the time of hypotension and poor cardiac output from infarction. The other patient had paralysis of both legs, right arm, and was aphasic after operation. Death in this patient was due to pulmonary embolus, renal failure, heart disease, and wound infection, and the neurological problem may have been cerebral in origin from basilar artery disease rather than cord ischemia. Of the three survivors, one recovered, one became completely rehabilitated without special equipment, and one required braces and crutches to walk.

There was no correlation between aortic occlusion time and the development of neurologic deficits involving the lower extremities. Thus, this complication resulted from interruption of cord blood supply, evidenced by the fact that it occurred only in those patients in whom most of the thoracic and abdominal aortic segments were removed. Moreover, preservation of intercostal and lumbar arteries reduced this complication to about one-third and significantly reduced its severity (Table 4).

TABLE 2. *Renal Function After Operation Correlation With Renal Artery Occlusion Time (78 Patients Leaving Operating Room)**

Occlusion Time (Minutes)	Patients	Renal Dysfunction	Dialysis
15–35	28 (36%)	4 (14%)	1
35–55	44 (56%)	1 (2%)	0
55–150	6 (8%)	2 (33%)	2†
Total	78 (100%)	7 (9%)	3 (4%)

* One patient on chronic hemodialysis. †Death occurred in one patient.

Long-term Results

These patients have been followed from 30 days to 17 years; and of the 77 survivors, information to time of death or to the present is available in 73 (95%). Of the survivors, 51 (62%) are alive and well. Although the majority of patients have been treated during the past five years, 24 were treated at longer intervals and 15 (60%) of these patients lived for periods ranging from five to 17 years. An actuarial curve was constructed from this information and survival projected for a six-year period and compared to that of patients surviving simple infrarenal abdominal aortic resection.[10] The patients in this series with extensive aneurysm operation compare favorably with those with more localized simple aneurysm resections (Fig. 17). Of interest is the fact that the four patients in whom surgery was not advised, due to risks imposed by associated disease, died of aneurysmal rupture from seven to 18 months after the decision was made for conservative treatment.

Discussion

In our own experience, graft inclusion and direct visceral artery orifice reattachment has proved to be the most simple method of treating extensive aneurysms of the thoracoabdominal aorta and of the abdominal aortic segment from which the visceral vessels arise. This method significantly reduced hte dissection required for operation and the number of anastomoses required by other techniques. Finally, closing the

TABLE 3. *Resumption Urine Excretion After Renal Artery Occlusion* (Correlation With Periods of Occlusion)*

Renal Artery Occlusion (in minutes)	Urine Flow Resumptions (mean time, in minutes)
20–30 (14 patients)	25
30–40 (8 patients)	20
40–45 (10 patients)	21

* Indigo carmine clearance time.

TABLE 4. *Paraplegia Correlation with Preservation of Intercostal and Lumbar Arteries (22 Patients with Extensive Involvement Thoracic and Abdominal Aorta)*

Intercostal and lumbar artery reattachment	No. patients	Paraplegia				
		Total cases	Mild	Moderate	Severe	Other
Successful	14	2 (14%)	2	0	0	0
Not accomplished	8	3 (38%)	0	1	2	2
Not successful	(3)	(1)	(0)	(0)	(1)*	(1)
No attempt	(5)	(2)	(0)	(1)	(1)†	(1)
Total	22	5 (23%)	2	1	2	2

* Paraplegia occurred 18 hours after operation with hypotension from myocardial infarction. †Neurologic deficit may have been due to stroke.

aneurysmal wall around the graft has reduced bleeding from the anastomoses and graft, and has separated the graft from adjacent viscera, preventing erosion into the gastrointestinal tract. The time necessary for operation and the associated blood loss both during and after operation has been significantly reduced. Consequently the survival after operation approaches that after operations for less extensive lesions of the distal abdominal aorta and, indeed, the long-term survival is the same. Although there have been no significant complications in the treatment of the last 22 patients, disturbance in renal and spinal cord function continues to be a threat. Hypothermia and temporary shunts do not offer additional protection from the latter evident by previous studies.[8] Moreover, these adjuncts do not offer significant protection to preservation of renal function. For example, renal injury and failure has occurred after their use in the treatment of thoracoabdominal aortic aneurysms.[12] Temporary renal perfusion techniques have been employed in the renal transplant field and successfully employed in single case reports in the treatment of thoracoabdominal aortic aneurysms.[1,18] These techniques vary from a simple injection of electrolyte solution into the excluded aorta with attached renal artery to individual renal artery perfusion continuously during operation.[2,18,19] In fact, the kidney was removed, perfused for four and one-half hours during aneurysm resection and then reinserted as graft by one group who, on the basis of this one case, recommends this as the method of choice.[24] In light of the fact that only one patient died in this series, with renal insufficiency being only a part of his problem, we plan to continue efforts of improving technique of accurately restoring renal circulation as rapidly as possible while maintaining blood volume and normal state of hydration.[21] Finally, renal insufficiency has been observed in major operations not involving renal artery occlusion and has been particularly troublesome after infrarenal abdominal aortic operations for ruptured aneurysm.[22] There were 12 patients (14%) in this series with ruptured aneurysms. Consequently, our renal function experience in this series of 82 patients would appear to be very acceptable, considering the age group and the nature and extent of pathology treated.

Acknowledgments

Grateful acknowledgment is given for illustrations to Mr. Barry Baker, Department of Medical Illustration and Audiovisual Education, Baylor College of Medicine, Houston, Texas.

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Discussion

Dr. Harris B. Shumacker (Indianapolis, Indiana): On rare occasions, there are presented experiences so startling in their break with traditional management and so excellent in outcome, one can only gasp with amazement. Such is the report of Crawford and his associates. Their present extensive series of cases confirms the conclusions reached in the earlier report.

When one relives the days when fear of paraplegia accompanied all but the briefest operations necessitating aortic cross-clamping in the absence of collaterals such as prevail in coarctation, and the efforts to protect the cord by cooling, various perfusion techniques, and arterial shunting, one realizes how truly remarkable this new approach is. Obviously, the direct attack upon the aneurysm, without need for such ancillary protective aids, or anticoagulants, saves time and blood. The use of buttons of aortic or aneurysmal wall giving rise to one or more major branches has proved useful to others, as it has to the Crawford group.

Their suggestion regarding restoration of blood flow to intercostals and lumbars is patently an important innovation. The results obtained confirm the opinion generally held that the proximal branches are much more important in preserving cord function than the more distal ones. It will be interesting to learn whether these and future observations confirm the supposedly enormous importance of the artery of Adamkiewicz, as well as that of the anterior spinal artery.

Most of us have feared cases involving the entire descending thoracic and abdominal aorta because paraplegia seemed almost inevitable. They have shown this not to be true. To be sure, their only instances of paraplegia were in this group of 22 cases, but then only in five. Furthermore, their reconstitution of blood flow to intercostal and lumbar arteries seems to have lessened the risk by at least half.

They have shown that cases previously thought inoperable or only partially resectable are, indeed, curable. They have demonstrated that they can treat these life-threatening aneurysms with a very low mortality, in contrast to the high risk which has generally prevailed.

Obviously, their work should be expanded. Others who operate well and without wasting time might see if they can duplicate these fantastic results. Almost certainly, no one who operates slowly and tediously should undertake to do so.

The Crawford group deserves our most hearty congratulations for a truly inspiring contribution.

Dr. John Connolly (Irvine, California): First I'd like to congratulate Dr. Crawford on his superb operative results with one of the most technically challenging lesions that we're asked to operate on. I think that, perhaps, because most of us are not as quick and as technically facile as Dr. Crawford, we might approach the lesions that he listed today a little more conservatively, and I for one always have a heparinless shunt available.

Now to give you some idea of the incidence of suprarenal involvement and thoracic involvement, I'd like to note our findings in a series of aortograms. In 132 consecutive aortograms in patients with palpable abdominal aneurysms, we noted that there were 31% who had multiple aneurysms. If we look to see what these multiple aneurysms are, it's of importance that four of the 132 or 3.8%, appear to extend above the renal arteries, and six, or 4.5%, also involve the thoracic area.

If we look at what did we do to these four, some years ago we would have tried to resect these completely, as described by Dr. Crawford. In one of the four we did so. We resected the entire aorta, reconstructing mesenteric and renal arteries, as mentioned today, using a similar technique, but with a shunt. In one case we found that the aneurysm that was above the renals could be managed by a plication, without resection of any of the mesenteric or renal vessels. In one case we decided that the suprarenal widening was not too dangerous and we left it alone and did an infrarenal resection with graft replacement. In one case we decided that the involvement above the renals did not warrant a suprarenal operation because of the general poor condition of the patient.

In the group with thoracic involvement, in one case we decided that the patient's general condition did not warrant a thoracoabdominal operation, but in the other five cases we decided to do an infrarenal resection as the first procedure and then as a separate operation later we resected the thoracic aneurysm.

I would like to call to your attention the work of Wakabayashi of our Department. His contribution has been twofold: 1) to leave the back wall of the distal aorta—and I noted that Dr. Crawford does the same thing, and 2), the use of a nonthrombogenic shunt during the operation because we do not operate as rapidly as Dr. Crawford.

I think a shunt should always be available. There may be instances where you don't need it, but in our hands, we've found it to be very helpful. It can be either placed in the atrium proximally, or directly into the aorta through a purse-string suture with distal return to a femoral artery. The important thing is that it should be a big shunt so that you can equalize pressures above and below.