Aneurysm of Thoracoabdominal Aorta Involving the Celiac, Superior Mesenteric, and Renal Arteries. Report of Four Cases Treated by Resection and Homograft Replacement *

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MOST aneurysms of the abdominal aorta fortunately arise below the origin of the renal arteries, so that resection is not associated with serious ischemic damage to vital structures.[10] In the small proportion of cases, however, in which the aneurysm is located in the upper segment of the abdominal aorta including its major visceral branches, this problem assumes grave significance. In such cases there is considerable danger of producing fatal ischemic damage to such vital structures as the liver, kidneys, and gastro-intestinal tract, as a consequence of temporary arrest of blood flow to these organs during the period required to excise the aneurysm and replace it with an aortic homograft.

This report is concerned with our experiences with resection of aneurysms of this latter type and replacement by homografts in four cases. The aneurysms in all of these cases extended from the lower descending thoracic aorta to the lower abdominal aorta and involved the celiac, superior mesenteric, and one or both renal arteries. So far as we have been able to determine from a review of the literature, there have been no records of similar cases in which all these vessels were involved, although two cases with involvement of some of these vessels were recently reported. In one of these the aneurysm arose below the origin of the normally placed left renal artery but involved the renal artery of an ectopic right kidney, and it was successfully resected and arterial continuity to the right kidney restored after replacement with a homograft.[21] In the other case the aneurysm, involving the celiac, superior mesenteric, and left renal arteries, was successfully resected and the segment replaced with a homograft so that continuity to the celiac and superior mesenteric arteries was restored but the left kidney was excised.[22]

In the four cases to be reported the operative procedure consisted in excision of the aneurysm and replacement with an aortic homograft with restoration of continuity to the celiac axis and superior mesenteric arteries in all, as well as to both renal arteries in two and to one of the renal arteries in the other two cases. Because of the extensive nature of this operative procedure and the problems it poses in terms of technical management as well as functional disturbances of vital organs, it seems desirable to record these cases and to consider certain observations derived from this experience, relating particularly to surgical management and to significant studies on renal and hepatic function.

* Presented before the American Surgical Association, White Sulphur Springs, West Virginia, April 11–13, 1956.

Supported in part by the Houston Heart Association.

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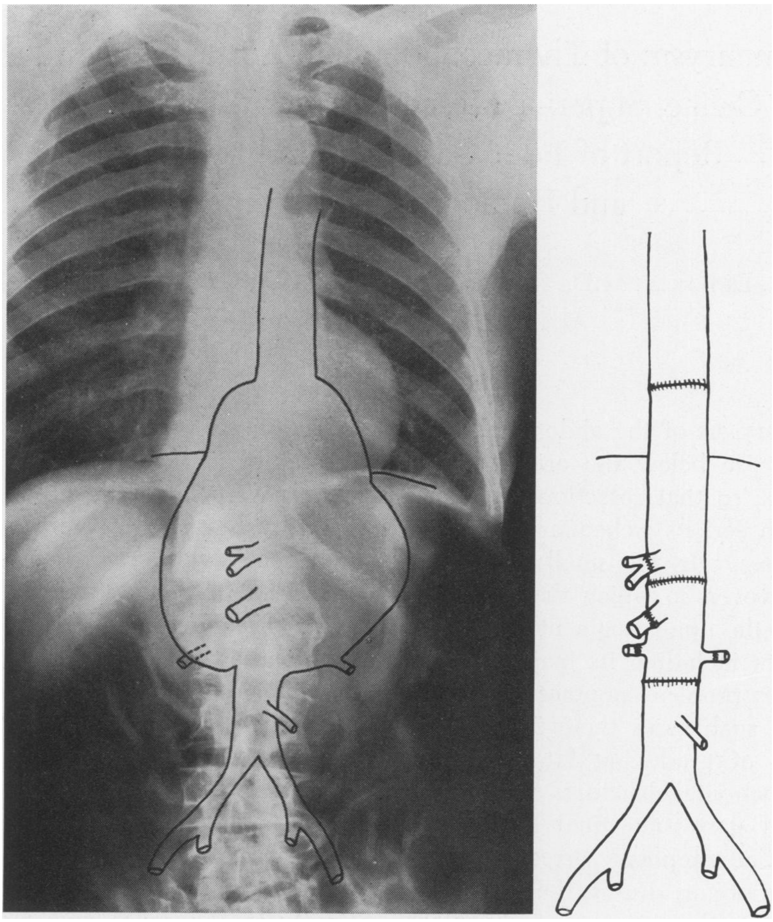

FIG. 1. Composite roentgenogram of the chest and abdomen with diagram superimposed to show location and extent of the thoracoabdominal aneurysm in Case 1. Replacement of the excised segment of aorta and aneurysm by homograft with restoration of continuity of the aorta, celiac, superior mesenteric, and renal arteries is shown in the diagram on the right.

CASE REPORTS

Case 1. J. H., a Negro farmer 66-years-old, was admitted to the Houston Veterans Administration Hospital Aug. 10, 1955, because of pain in the abdomen, left flank and back, of 2 years' duration. The pain initially was felt only in the upper portion of the abdomen but gradually extended to the back and left flank. The patient had lost about 30 pounds in weight during his illness and had had to discontinue farming because of failing strength.

The patient had had gonorrhea and probably a penile lesion, the nature of which could not be accurately ascertained.

On admission the blood pressure was 158 mm. Hg systolic and 100 mm. Hg diastolic. The heart was not enlarged and no murmurs were detected. The abdomen was somewhat protuberant, particularly in the epigastrium, where vigorous pulsations were visible. Palpation disclosed a firm mass in the upper part of the abdomen extending from the xiphoid process almost to the umbilicus. It was somewhat irregular in outline, with an expansile pulsation. A systolic murmur was audible over the entire mass.

Roentgenographic examination of the chest and abdomen revealed a large soft-tissue shadow extending from the level of the eleventh thoracic to the third lumbar vertebra (Fig. 1). The bodies of the twelfth thoracic and first and second lumbar vertebrae were extensively eroded (Fig. 2). An aortogram disclosed a large dumbbell-shaped aneurysm extending from the ninth thoracic vertebra to the second lumbar vertebra. The waist of the dumbbell appeared to be at the level of the aortic hiatus of the diaphragm. Intravenous pye-

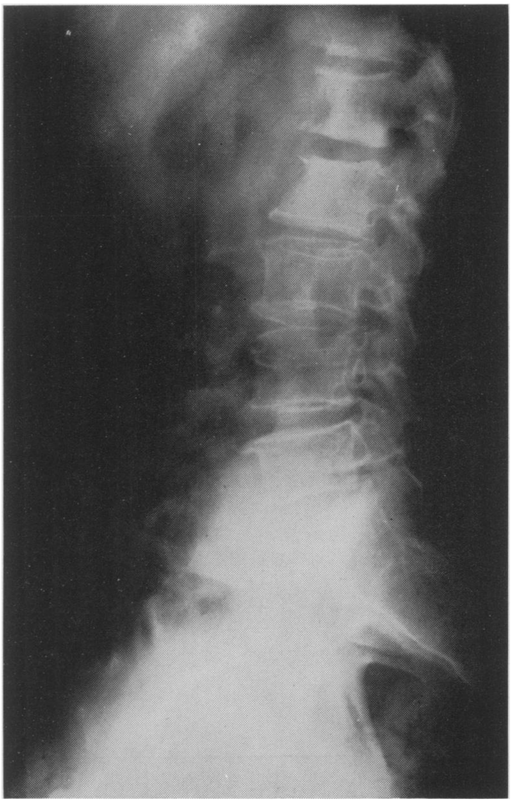

FIG. 2. Lateral roentgenogram of the abdomen in Case 1 showing erosion of the bodies of the twelfth thoracic, first and second lumbar vertebrae.

lography outlined the collecting systems of both kidneys but failed to disclose their relationship to the aneurysm. An electrocardiogram showed normal sinus rhythm with slight evidence of left ventricular hypertrophy. Laboratory studies disclosed slight increase in the globulin fraction of the serum proteins and moderate reduction in platelet count.

On Aug. 31, 1955, operation was performed under general body hypothermia. Surface cooling was accomplished with a Thermo-O-Rite® blanket, the temperature having been reduced to 32.8° C. (91° F.). A left thoracolumbar approach was employed with entrance into the pleural cavity through the bed of the eighth rib. The pleural space was obliterated by dense fibrous adhesions, and posteriorly in the paravertebral gutter and adjacent mediastinum there was evidence of old and recent hemorrhage. The lower lobe of the lung was mobilized and retracted upward. The descending thoracic aorta was isolated about 6 cm. above the diaphragm and encircled with tape. The aneurysm was found to arise about 4 cm. above the diaphragmatic hiatus and extended well below the renal arteries. The posterior parietal peritoneum over the abdominal aorta and the ligament of Treitz were divided. The aorta below the aneurysm was encircled with umbilical tape. In order to expose the anterior surface of the aneurysm, it was necessary to remove the spleen and divide the attachments of the tail of the pancreas. The splenic flexure of the colon was mobilized, and retraction of the stomach and pancreas to the right and the colon downward exposed the aneurysm. The left kidney lay on the left anterior lateral wall of the sac, its vein passing laterally across the aneurysm to the inferior vena cava. The left kidney was dissected from Gerota's fascia and turned medially to expose the artery at the hilum. This vessel was then dissected medially and found to arise from the left lateral wall of the aneurysm about 5 cm. from its distal end. Mobilization of the left renal vein exposed the right renal artery which also arose from the aneurysm. Superior mesenteric and celiac arterial trunks were next isolated and encircled with tapes.

Occluding clamps were applied to the aorta above and below the aneurysm and to the renal, superior mesenteric, and celiac arteries. The sac was then opened widely and excised except for the portion adherent to the eroded vertebral bodies. The major branches were diveded at their origin from the aneurysm to preserve maximum length. A segment of abdominal aortic homograft containing stumps of the renal, superior mesenteric, and celiac arteries was then used to bridge the defect and to restore continuity to all of these major vessels (Fig. 1). Following completion of these anastomoses the occluding clamps were released and normal circulation through the aorta was reestablished. The respective periods of arrest of circulation are shown in Chart III. The remnant of aneurysmal sac at the site of vertebral erosion was sutured along its margin for hemostasis. The omentum was then brought posteriorly and placed around the graft and into the vertebral defect. Penrose drains were placed into the vertebral bed of the aneurysm and brought out through a stab wound in the left flank. The diaphragm was repaired, an intercostal catheter was inserted into the left pleural space for underwater drainage, and the thoracic and abdominal wounds were closed.

During operation the rectal temperature drifted to 32.2° C. (90° F.). Rewarming was begun about one hour prior to completion of the operation, and the temperature returned to normal 4½ hours later. During the operation raw surfaces bled excessively. At that time the prothrombin time was 15 per cent, clotting time 45 seconds, and platelet count 100,000. Intravenous administration of 50 mg. of vitamin K-1 oxide caused prompt re-

CHART I. *Data Relating to Renal Function in Case 2*

CHART I

Determination	Before Operation	After Operation (days) 2	7	11	23
Urine Volume ml./24 hrs.	1000	162	1175	1150	1140
Urine Specific Gravity	1.023	1.024	1.014		1.013
Blood Urea Nitrogen mg. %	14	78	42	20	22
Urea Clearance	(1) 27%—normal max. clearance (2) 29%—normal standard clearance				
Renal Blood Flow ml./min.		29			644
Renal Plasma Flow ml./min.		16			389
Glomerular Filtration Rate ml./min.		1			69
Plasma Sodium meq./l.		141	133	138	144
Plasma Potassium meq./l.		5.9	4.3	4.0	2.6
Sodium Excretion meq./l.		8			8
Potassium Excretion meq./l.		12			30

duction in oozing and improvement in prothrombin and clotting times.

On the first postoperative day the patient was fully conscious, moved the extremities well, and appeared to be in good condition. The urinary output averaged about 7 ml. an hour.

On the second postoperative day urinary output remained about 7 ml. an hour and the blood urea nitrogen rose to 50 mg./100 ml. During the evening the patient developed severe acute pulmonary edema and was treated by venesection with removal of 500 ml. of blood and administration of aminophyline, norepinephrine, and oxygen under positive pressure. The patient's condition gradually improved, but it was necessary to continue intravenous administration of norepinephrine.

At 3 a.m. on the third postoperative day, severe pulmonary edema again developed and the patient became unconscious. Tourniquets were applied to the extremities, tracheostomy was performed, and oxygen was administered under pressure with a Halliburton positive pressure, demand-assist valve. The blood urea nitrogen had risen to 70 mg./100 ml. The urinary output was increased, however, to a total of 440 ml. in 24 hours.

On the fourth postoperative day the patient's general conditon remained about the same. There was, however, a significant rise in the total urine volume for the 24 hour period, the amount being 1,183 ml. Urinary steroid excretion studies showed a significant reduction in adrenal cortical activity; therefore, an infusion of 100 mg. of cortisone was given.

Bronchopulmonary secretions remained a problem throughout the next day although there appeared to be slight improvement. The blood urea nitrogen had risen to 96 mg./100 ml. Throughout the day the urinary output remained at a high level, 1,066 ml. having been excreted during the 24 hour period. However, renal blood flow, renal plasma flow, and glomerular filtration rate were reduced to negligible levels, the actual figures being 22 ml. per minute, 12 ml. per minute, and 4 ml. per minute, respectively. Serum bilirubin had increased to 4.4 mg. and cephalin flocculation to 2+.

Six days after operation the patient was still stuporous although he responded somewhat to painful stimuli. The blood urea nitrogen had risen to 124 mg./100 ml. and the hourly urinary volume gradually declined. A total of 500 mg. of cortisone was given intravenously. Although the total urinary volume for the 24 hour period was 522 ml., during the last 2 or 3 hours the urinary output was zero.

The patient's condition rapidly deteriorated on the seventh postoperative day, manifested by pro-

CHART II. *Studies of Hepatic Function Before and After Operation in the Cases Reported Herein*

CHART II. *Studies of Liver Function*

Determination	Case 1 (105 min.)* Control	P.O. 1	P.O. 5	Case 2 (36 min.)* Control	P.O. 19	Case 3 (47 min.)* Control	P.O. 5	Case 4 (102 min.)* Control	P.O. 7	P.O. 9
Bilirubin	0.5	1.1	4.4	0.7	0.3	0.7	1.3	0.4	2.2	2.0
Ceph. Flocc.	Neg.	1+	2+	Neg.	2+	Neg.	2+	Neg.	2+	2+
Thymol Turbidity	2	1	1	2	1	4.3		1	1	1
Alk. Phosphatase	3.5		4.3	4	3	3.5		3.1		11.0
Serum Protein	8.5			6.5	6.0	6.6	5.3	5.5	4.5	4.2
Prothrombin	85%	80%	80%	100%	75%	55%	100%	95%	45%	50%

* Period of simultaneous occlusion of aorta, celiac and superior mesenteric arteries.

gressive fall in blood pressure despite vasopressor agents and by complete anuria. Pulmonary edema became overwhelming and the patient died at 3:50 a.m. on Sept. 7, 1955.

At necropsy there were bilateral pulmonary edema and pneumonitis. With the exception of multiple small hemangiomas the liver was normal. The kidneys were swollen and pale, and on microscopic examination there was hyalinization of glomeruli and necrosis of tubules. The homograft was intact and patent.

Case 2. C. B. M., a man 65-years-old, was admitted to the Houston Veterans Administration Hospital on Oct. 13, 1955, for treatment of an aneurysm involving the lower thoracic and upper abdominal aorta. About 18 months previously, severe pain had developed in the left subcostal area, which seemed to be precipitated by sitting or standing. At first the pain was relieved by lying on the right side, but in recent months it had been unaffected by change in position and had increased in severity, involving also the left flank and upper lumbar region. About 6 weeks previously, the patient had been admitted to another hospital, where roentgenograms revealed an aortic aneurysm.

The patient had no knowledge of previous syphilitic infection.

The blood pressure on admission was 120 mm. Hg systolic and 80 mm. Hg diastolic. His chest was emphysematous and slightly asymmetric owing to prominence of the left anterior costal margin. However, expansion was equal bilaterally. In the epigastrium, and particularly beneath the left costal margin, vigorous aortic pulsations were evident, although a definite mass was not felt.

Laboratory studies revealed slight albuminuria and hematuria. The erythrocyte count was 4,000,000, hemoglobin 13.7 grams, and leukocyte count 5,250, with a normal differential count. Blood urea nitrogen was 14 mg./100 ml., and urea clearance was normal (Chart I). Hepatic function studies were also normal (Chart II). Results of the serologic test for syphilis were positive. Postero-anterior and lateral roentgenograms of the chest and abdomen revealed a large fusiform aneurysm of the lower thoracic and upper abdominal aorta, the walls of which were outlined by calcium (Fig. 3). At its origin the thoracic aorta was sharply angulated to the left, and distally the aneurysm appeared to extend as far as the third lumbar intervertebral space, displacing the esophagus and stomach anteriorly (Fig. 3). The vertebral bodies were not eroded. Intravenous pyelograms showed normal excretory renal function and suggested that the renal arteries arose from the lower portion of the aneurysm.

On Oct. 19, 1955, operation was performed under general anesthesia. A left thoracolumbar approach was used with the pleural cavity being entered through the bed of the resected seventh rib. Preliminary exploration disclosed a large fusiform aneurysm arising in the lower third of the thoracic aorta and extending into the left hemithorax. There was sharp angulation of the thoracic aorta just proximal to the origin of the aneurysm. The greatest diameter of the aneurysm was at the level of the diaphragm, where it measured approximately 16 cm. The mediastinal pleura over the lower thoracic aorta was incised, the aorta was mobilized above the aneurysm, and a tape was passed about it. The aneurysm extended below the diaphragm for a distance of about 15 cm., its total length approximating 24 cm. The posterior peritoneum overlying the lower abdominal aorta was next incised together with the ligament of Treitz, the aorta in the region of the inferior mes-

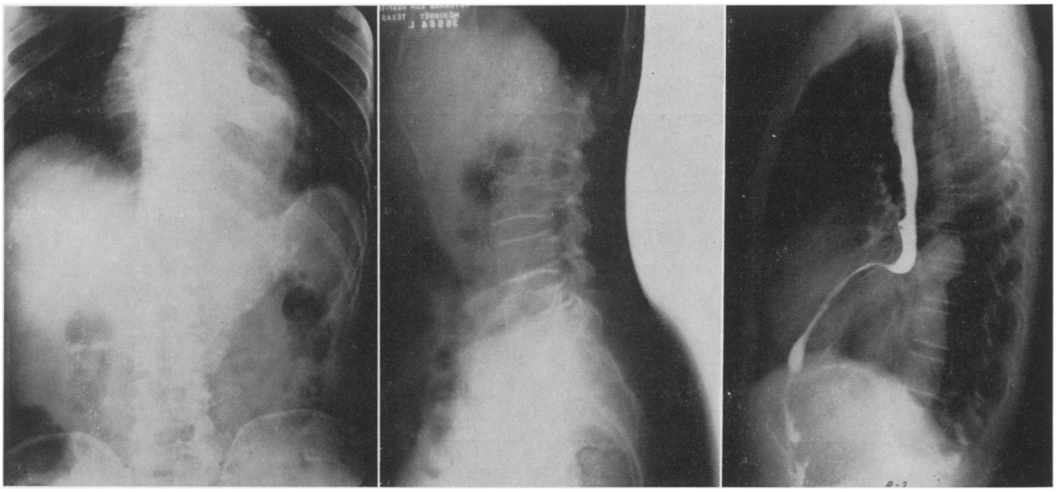

FIG. 3. Posteroanterior and lateral roentgenograms in Case 2 reveal a large fusiform aneurysm involving the lower thoracic and upper abdominal portions of the aorta. The walls of the aneurysm are outlined by calcium. The thoracic aorta is sharply angulated to the left at the upper end of the aneurysm. An esophogram with barium shows the esophagus to be displaced anteriorly by the aneurysm.

enteric artery was exposed, and a tape was passed about it. The parietal peritoneum was incised from the aortic hiatus, beneath the diaphragm to the left, behind the spleen, and downward in the left colic gutter. The spleen, splenic flexure of the colon, pancreas and stomach were then mobilized and retracted to the right, thus exposing the perirenal fat about the left kidney and the left retroperitoneal portion of the aneurysm. The left kidney was dissected from Gerota's fascia, its vein and artery were identified, and tapes were passed about them. From above the diaphragm the mediastinal pleural attachments to the aneurysm were incised and reflected, and the dissection was continued inferiorly to free the diaphragm and its crura from the aneurysm. The celiac, superior mesenteric, and right renal arteries were then isolated. With the exception of the inferior mesenteric artery, all major visceral branches of the aorta arose from the aneurysm (Fig. 4).

In order to minimize the period of arrest of visceral blood flow during resection of the aneurysm, a temporary shunt made of polyvinyl sponge, with an internal diameter of 14 mm. and approximately 40 cm. in length, was utilized. The shunt was attached to the descending thoracic aorta above the origin of the aneurysm by an end-to-side anastomosis and then similarly implanted into the abdominal aorta just above the level of the inferior mesenteric artery (Fig. 11c). The aorta proximal to the aneurysm was then doubly clamped and divided. Blood flow to the aneurysm and the branches arising from it now occurred by way of the shunt. Removal of the aneurysm was begun at its proximal end, but because of the thin necrotic posterior wall and the danger of hemorrhage from perforation, an occluding clamp was applied just proximal to the superior mesenteric artery and above the origin of the renal arteries and another occluding clamp applied to the celiac axis. Blood flow to the kidneys and superior mesenteric artery was thus maintained by the shunt, but blood flow to the celiac artery was interrupted. The proximal portion of the aneurysm between the occluding clamps was then removed, and the intercostal vessels arising from the posterior wall of its thoracic portion were secured by suture ligature. A portion of the posterior wall could not be completely excised, but the intimal layer with the attached laminated thrombi was removed. Occluding clamps were placed on the left renal artery, and it was divided. The left renal branch of the homograft was then anastomosed to this vessel (Fig. 12a). Occluding clamps were then placed on the abdominal aorta distal to the aneurysm and on the superior mesenteric and right renal arteries, and the remainder of the aneurysm was removed. The distal end of the homograft was anastomosed to the abdominal aorta, following which a noncrushing clamp was placed across the graft just above the left renal artery and just below its right renal branch and the occluding clamp on the abdominal aorta released to restore blood flow to the left kidney by way of the shunt (Fig. 12c). The graft was then anastomosed to the right renal artery, and the occluding clamp was moved above that vessel on the homograft to permit blood flow to the right

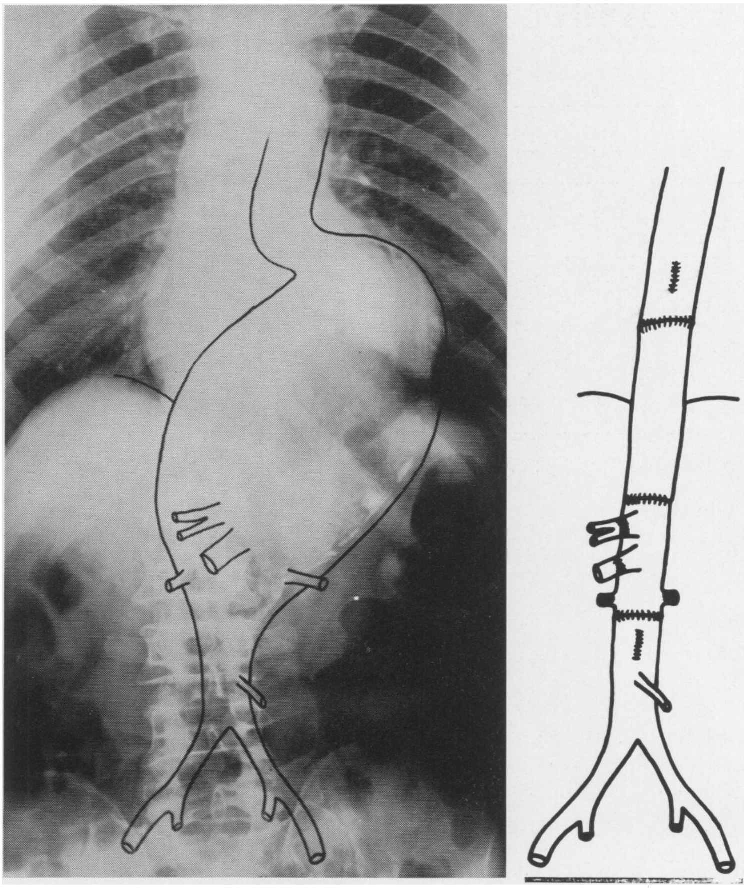

FIG. 4. Composite roentgenogram of the chest and abdomen with diagram superimposed to show location and extent of the thoracoabdominal aneurysm in Case 2. Replacement of the excised segment of aorta and aneurysm by homograft with restoration of continuity of the aorta. celiac, superior mesenteric, and renal arteries is shown in the diagram on the right.

kidney. This maneuver was repeated as the anastomoses to the superior mesenteric and celiac arteries were performed. The respective periods of arrest of circulation through these vessels are shown in Chart III. Anastomosis of the upper end of the graft to the thoracic aorta completed insertion of the graft. Occluding clamps were then removed to allow blood to flow in a normal fashion through the thoracic and abdominal portions of the aorta and into its major branches (Fig. 4). Exclusion clamps were reapplied, the shunt was removed, and the openings were closed with interrupted silk sutures (Fig. 5). Incisions in the posterior peritoneum over the abdominal aorta and beneath the diaphragm and in the left colic gutter were closed with continuous catgut sutures. The spleen was removed because of laceration. The aortic hiatus was then reconstructed, and the diaphragm was repaired. A catheter was inserted into the left pleural space through the eighth intercostal space for underwater drainage, and the thoracic and abdominal wounds were closed. A tracheostomy was then performed.

Operation lasted 8½ hours. During the procedure 4,500 ml. of whole blood was administered,

CHART III. *Periods of Occlusion of the Celiac, Superior Mesenteric, and Renal Arteries in the Cases Reported Herein in Minutes*

CHART III. *Period of Occlusion in Minutes*

Case No.	Celiac Artery	Superior Mesenteric	Right Renal	Left Renal
1	120	105	105	105
2	44	36	27	23
3	114	47	15	43
4	116	102	46	0

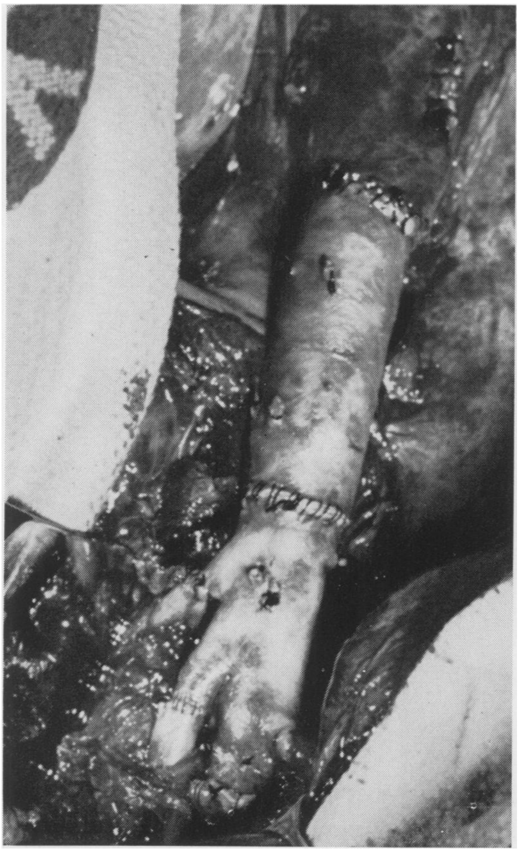

FIG. 5. Photograph made at operation in Case 2 showing the homograft in place. The celiac, superior mesenteric, and left renal arteries are visible, but the right renal artery lies behind the superior mesenteric artery. The proximal site of implantation of the shunt is just above the proximal aortic anastomosis.

FIG. 6. Intravenous pyelogram in Case 2 four months after operation reveals normal function of both kidneys.

and at the end of operation the patient's general condition appeared satisfactory.

During the first postoperative day, the urinary output was 15 ml. By the end of the second postoperative day, however, urinary output had increased to 162 ml. and renal function studies showed severe depression (Chart I). There was progressive increase in urinary volume during the next few days and by the fifth day the 24 hour urinary volume was 1,240 ml. The blood urea nitrogen reached a maximal level of 79 mg./100 ml. on the 3rd postoperative day and subsequently declined to a normal level by the 11th postoperative day. Renal function studies showed a return to normal on the 23rd day (Chart I) and liver function studies were essentially normal on the 19th day (Chart II).

Good peristalsis was evident on about the 4th postoperative day, and the patient was eating normally by the end of the 1st week. A necrotic area in the left groin resulting from extravasation of norepinephrine on the first postoperative day was debrided on the 26th postoperative day, and 15 days later the area was covered with a split thickness skin graft. The patient was discharged on Jan. 4, 1956, fully recovered and in good condition.

He returned for examination on Feb. 19, 1956. Intravenous pyelograms disclosed normal function of both kidneys (Fig. 6). Discrete renal function studies at this time were found to be normal, the actual figures for renal blood flow, renal plasma flow and glomerular filtration rate being respectively 792, 475 and 68 ml./minute. An aortogram

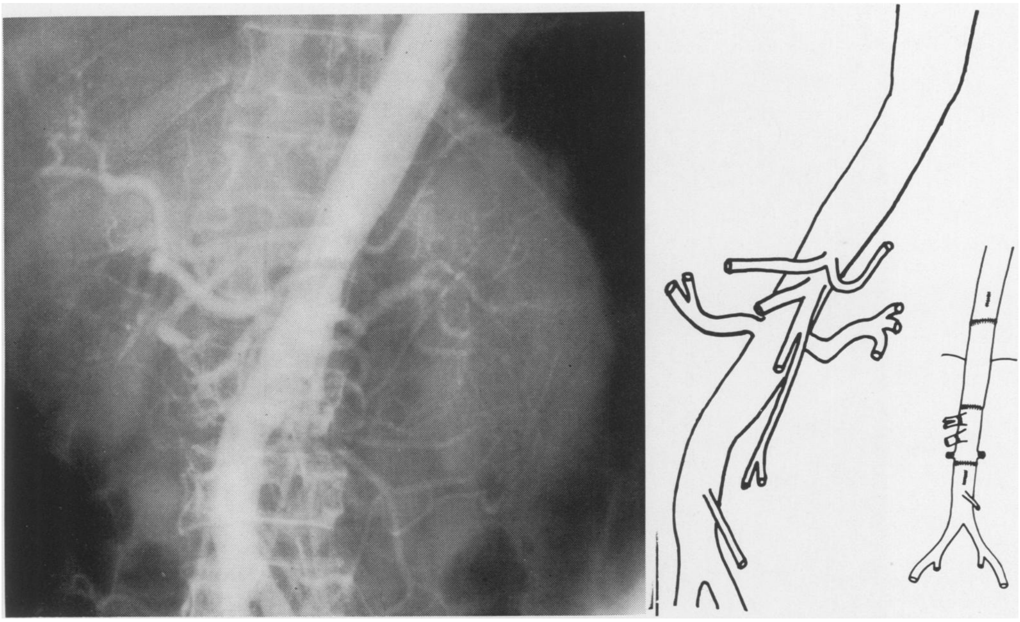

FIG. 7. Aortogram made five months after operation in Case 2 reveals normal patency of the aorta, celiac, superior mesenteric and renal arteries.

on March 23, 1956 demonstrated patency and normal filling of the renal, superior mesenteric, and celiac arteries (Fig. 7).

Case 3. P. T., a man 42-years-old, was admitted to the Methodist Hospital on Nov. 5, 1955, complaining of a sense of fulness and increasing pain in the upper part of the abdomen of one year's duration. During the preceding 4 months, the pain had become so severe that large doses of narcotics were necessary for relief. The pain, which was most severe in the epigastrium and left upper abdominal quadrant, was not related to eating and was not relieved by antacids. An aortogram made at another hospital 3 months previously had disclosed an aneurysm of the lower thoracic and upper abdominal portions of the aorta. Operation was performed at that time, but because the aneurysm involved the renal arteries, it was not resected.

The patient had had brucellosis many years previously and was known to have had hypertension for one year prior to admission. There was no history of venereal disease.

On admission, the blood pressure was 180 mm. Hg systolic and 130 mm. Hg diastolic. An operative scar extended in an oblique direction from the umbilicus to the left costal margin. Examination of the abdomen was difficult because of extreme tenderness in the epigastrium, although a pulsating mass was palpable.

The only significant laboratory findings were a few granular casts and a trace of albumin in the urine. Roentgenograms of the chest showed a soft tissue mass in the posterior mediastinum protruding to both the right and left of the spine (Fig. 8). Abdominal films showed the mass to protrude to the left of the lumbar spine at the level of the third and fourth lumbar vertebrae. Calcification was present in the peripheral portions of the mass. Intravenous pyelograms revealed a normal kidney and ureter on the right but poor concentration on the left. An electrocardiogram disclosed normal sinus rhythm with slight left ventricular hypertrophy and slightly prolonged P–R interval.

On Nov. 10, 1955, operation was performed through a left throacoabdominal approach with excision of the previous scar. Upon retracting the lung anteriorly, the mid-descending thoracic aorta was found to be sharply angulated in a horseshoe fashion. At the lower end of this angulation was a large aneurysm, which extended distally through the diaphragm.

The descending thoracic aorta above the aneurysm was mobilized, and a tape was placed about it. The spleen was resected, and an incision was made in the left lateral posterior peritoneum; this detached the splenic flexure of the colon and permitted retraction of the stomach, colon, and pancreas to the right. Gerota's fascia was incised, and the left kidney was mobilized from its bed and retracted to the right and inferiorly. The left renal artery was isolated and was found to arise from the lower portion of the aneurysm. The ligament of Treitz and the posterior peritoneum overlying the abdominal aorta in the region of the inferior

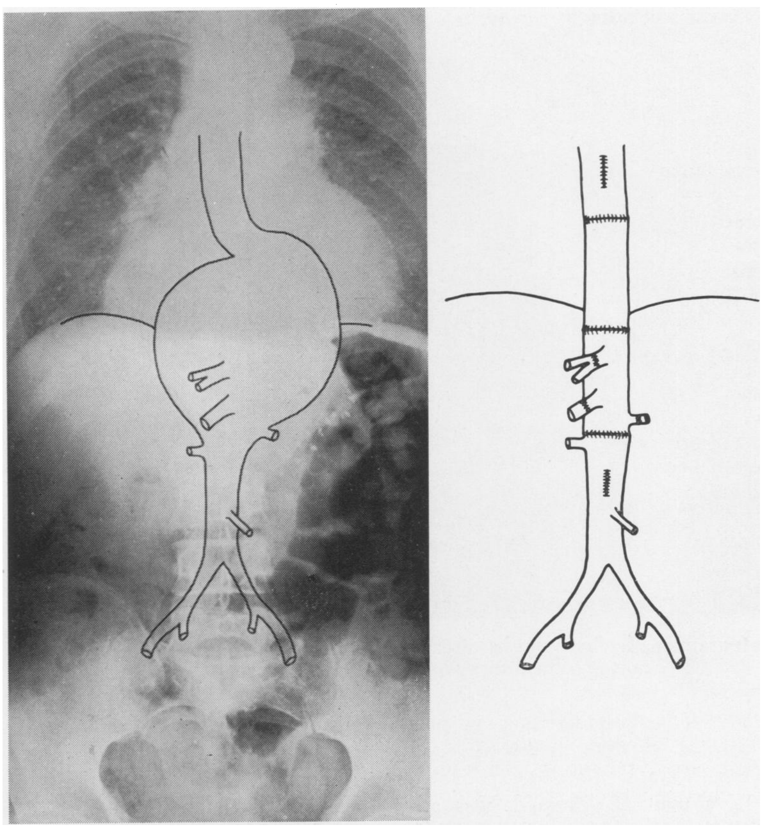

FIG. 8. Composite roentgenogram of the chest and abdomen with diagram superimposed to show location and extent of the thoracoabdominal aneurysm in Case 3. Replacement of the excised segment of aorta and aneurysm by the homograft with restoration of continuity of the aorta, celiac, superior mesenteric and left renal arteries is shown in the diagram on the right.

mesenteric artery were incised. The lower abdominal aorta was mobilized, and a tape was placed about it distal to the aneurysm. The aneurysm was then mobilized by removal of the diaphragmatic attachments to its surface, and the superior mesenteric and celiac arteries were isolated. The aneurysm extended distally to a point just beyond the origin of the left renal artery but above the origin of the right renal artery (Fig. 8). A shunt of compressed polyvinyl sponge was then anastomosed to the side of the descending thoracic aorta above the aneurysm and to the anterior aspect of the abdominal aorta below the aneurysm. The left renal artery was then divided at its origin from the aneurysm, and the left renal branch of a lyophilized homograft was anastomosed to it. Occluding clamps were placed on the descending thoracic aorta above the aneurysm, on the abdominal aorta just proximal to the right renal artery and on the celiac and superior mesenteric arteries, and the aneurysm was excised. The distal portion of the abdominal aortic homograft was anastomosed to the abdominal aorta. The homograft was then occluded above the renal arteries. Upon removal of the abdominal aortic clamp, blood flow to the kidneys was restored through the shunt.

The superior mesenteric and then the celiac arteries were next anastomosed to the graft, following which the homograft was anastomosed to the lower end of the descending thoracic aorta, and the occluding clamp on the aorta removed with resultant restoration of normal blood flow (Fig. 8). The periods of occlusion for the left renal, superior mesenteric, and celiac arteries are shown in Chart III. The shunt was removed and the aortotomy wounds were closed. The posterior remnant of the wall of the aneurysm was oversewn with a continuous suture for hemostasis, a pedicled omental graft was wrapped about the homograft, and the posterior peritoneum over the abdominal aorta was closed with a continuous suture. The left kidney was replaced in its bed and the peritoneum in the left gutter was reapproximated. Appendectomy was then performed.

CHART IV. *Data Relating to Renal Function in Case 3*

CHART IV

Determination	Before Operation	After Operation (days) 2	7	11	22
Urine Volume ml./24 hrs.	1000	306	3595	5560	1800
Urine Specific Gravity	1.026	1.013	1.010		1.014
Blood Urea Nitrogen mg. %	20	60	80	27	
Renal Blood Flow ml./min.	461	212	396		596
Renal Plasma Flow ml./min.	277	121	226		358
Glomerular Filtration Rate ml./min.	67	19	44		59
Plasma Sodium meq./l.	122	128	132	132	128
Plasma Potassium meq./l.	5.2	3.8	4.3	4.3	3.5
Sodium Excretion meq./l.	63	61	280		101
Potassium Excretion meq./l.	40	62	52		38

The diaphragm was repaired, and an intercostal drainage tube was inserted through the ninth intercostal space and connected to water sealed drainage. The wound was then closed. A catheter was placed in the right side of the chest through the fifth intercostal space, since the right hemithorax had been entered through the mediastinum during the procedure. The patient received 6,500 ml. of whole blood during the procedure, which lasted about 7 hours. At the conclusion of the operation the blood pressure was 150 mm. Hg systolic and 90 mm. Hg. diastolic.

Within the first 90 minutes after operation, 250 ml. of urine was excreted, and urinary output continued at a rate of 5 to 20 ml. per hour during the first 48 hours (Chart IV). By the 4th day, the urinary volume had reached 1,820 ml. with maximal diuresis on the ninth day, when 5,950 ml. of urine was excreted. Subsequently, the output declined to normal levels. The blood urea nitrogen level had risen to 100 mg. on the 5th day but returned to normal by the tenth day. Glomerular filtration rate was severely reduced on the day after operation but returned to normal by the 22nd day. Peristaltic activity became normal by the 4th postoperative day, when the nasogastric tube was removed. Hepatic function studies revealed a slight increase in serum bilirubin and a cephalin flocculation of 2+ (Chart II).

After the first postoperative week the patient required only occasional small doses of codeine and by the 10th postoperative day he was completely ambulatory, asymptomatic and taking a normal diet. He was discharged on Dec. 4, 1955, in good condition. On Mar. 31, 1956, excretory pyelograms were normal.

Case 4. A. G., a white man 65-years-old, was admitted to the Houston Veterans Administration Hospital Oct. 25, 1955, for treatment of a thoracoabdominal aneurysm, diagnosed about 2 months previously at the time of subtotal gastric resection for peptic ulcer.

On admission, the blood pressure was 130 mm. Hg systolic and 90 mm. Hg diastolic. Examination revealed a well healed upper abdominal midline incision and a palpable pulsating mass in the left upper abdominal quadrant. Laboratory findings were essentially normal. Roentgenograms of the chest revealed no abnormalities, but an anteroposterior roentgenogram of the abdomen disclosed calcification of the wall of the aneurysm (Fig. 9). Aortography, performed through a catheter passed through the left brachial artery into the thoracic aorta, revealed aneurysmal involvement of both the lower thoracic and upper abdominal portions of the aorta. Intravenous pyelograms were normal, although discrete renal function studies disclosed slight reduction in glomerular filtration rate. No abnormalities were detected in the electrocardiogram.

On Nov. 12, 1955, operation was performed through a left thoracoabdominal approach. Exploration revealed a fusiform aneurysm involving

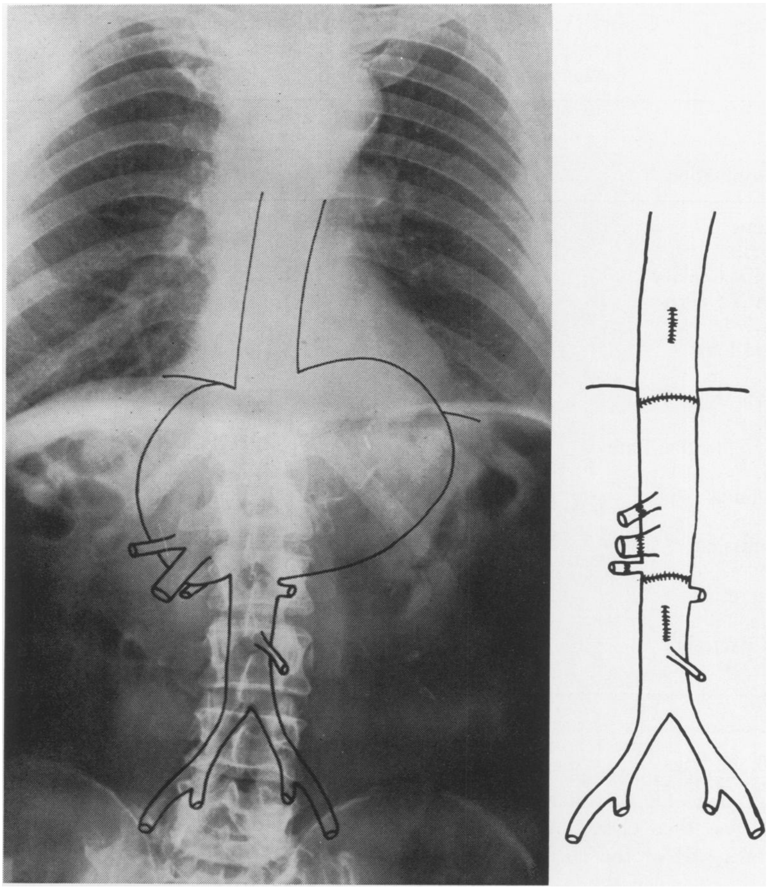

FIG. 9. Composite roentgenogram of the chest and abdomen with diagram superimposed to show location and extent of the thoracoabdominal aneurysm in Case 4. Replacement of the excised segment of aorta and aneurysm by the homograft with restoration of continuity to the aorta, celiac, superior mesenteric and right renal arteries is shown in the diagram on the right.

the distal third of the descending thoracic aorta and extending through the diaphragm to include the upper abdominal aorta. The thoracic aorta above the aneurysm was mobilized, and a tape was passed about it. The diaphragm was then incised to the surface of the aneurysm. The posterior peritoneum beneath the left leaf of the diaphragm was incised laterally, the incision continuing behind the spleen and down the paracolic gutter as far as the sigmoid colon. The stomach, spleen, pancreas and colon were then mobilized and retracted to the right to expose the left anterolateral surface of the aneurysm and distal abdominal aorta below. The posterior peritoneum over the lower abdominal aorta was incised just above the inferior mesenteric artery, the aorta below the aneurysm was mobilized, and a tape was passed about it. The left renal vein was then isolated and mobilized. The left renal artery was exposed and found to arise just distal to the aneurysm. The right renal artery, however, had its origin from the aneurysmal sac about 4 cm. from its distal end. The superior mesenteric and celiac arteries arising from the aneurysm were likewise exposed and mobilized, and tapes were passed about them. With exclusion clamps, a temporary by-pass shunt of compressed polyvinyl sponge was then implanted into the aorta above and below the aneurysm (Fig. 10). With blood flow established through the shunt, occluding clamps were applied to the aorta above the aneurysm just distal to the shunt and below to the aneurysm at a level above the origin of the left renal but below the origin of the right renal artery. After occlusion of the superior mesenteric and celiac arteries, the aneurysm was opened widely and excised. A lyophilized abdominal aortic homograft containing the right renal, celiac, and superior mesenteric arteries was utilized to replace the excised segment of aorta. The right renal branch of the homograft was first

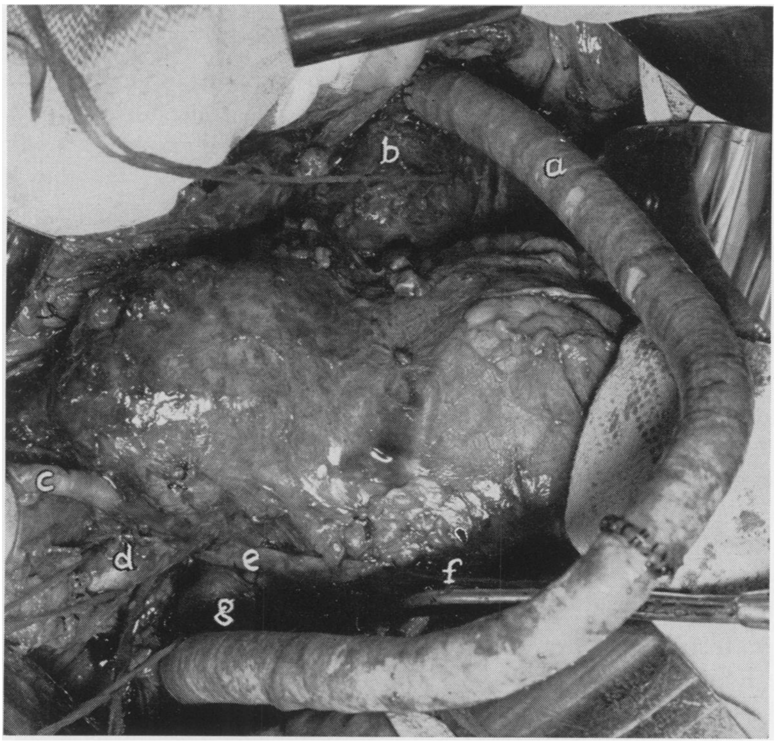

FIG. 10. Photograph made at operation in Case 4. The shunt (*a*) has been implanted into the thoracic aorta above (*b*) and into the abdominal aorta below (*g*). The celiac (*c*) and superior mesenteric (*d*) arteries have been isolated and tapes passed about them. The left renal vein (*e*) crosses the lower portion of the aneurysm. The left renal artery has been identified and a tape (*f*) passed about it.

anastomosed to the right renal artery, after which the distal end of the aortic homograft was anastomosed to the distal segment of aorta. By removal of the occluding clamp above the origin of the right renal vessel, blood flow was restored to the right kidney, flow to the left kidney not having been interrupted during the procedure. Anastomosis of the superior mesenteric artery to the graft was completed, and following this the celiac artery was anastomosed to the graft. The proximal anastomosis between the homograft and the thoracic aorta was next completed (Fig. 9). The shunt was removed, the abdominal viscera were replaced, and the posterior peritoneum was approximated. Several rubber drains were placed into the bed of the aneurysm along the eroded surface of the vertebral bodies and brought out in the left flank. The diaphragm was then repaired, an intercostal catheter was inserted into the left pleural space for underwater drainage, and the wound was closed. The periods of occlusion for the celiac, superior mesenteric, and right renal arteries are shown in Chart III.

Following operation, the blood pressure remained at preoperative levels. The urinary volume for the first postoperative day was 199 ml. and the blood urea nitrogen was 33 mg./100 ml. Subsequently, the daily urinary volume progressively increased to 2,020 ml. by the 8th postoperative day. Blood urea nitrogen increased to 136 mg. per 100 ml. on the 8th day and began to decline thereafter. Hepatic function studies showed some deviations from normal, but his general condition was satisfactory (Chart II). By the 8th postoperative day the patient was ambulatory, taking a soft diet, and asymptomatic. During the following week his condition seemed to be daily improving, and arrangements for his discharge were being made.

On the 13th postoperative day, the patient began to have bloody diarrheal stools and on the following day vomited a large quantity of bright red blood and became hypotensive. At abdominal exploration, the site of bleeding was found to be a marginal ulcer at the gastrojejunostomy. The ulcer was resected, but the patient became hypoxic and died after cardiac arrest developed. At necropsy, all the anastomoses were patent, and both kidneys appeared relatively normal.

DISCUSSION

There are two important considerations in extirpation of aneurysms of this type, stemming primarily from the location and extent of the lesion. The first of these is concerned with the technical performance of the procedure and the second with the potential ischemic damage to such vital abdominal organs as the kidneys, liver, and gastrointestinal tract as a result of temporary arrest of circulation to them during performance of the procedure. The former has an important bearing upon the latter, since ischemic damage to tissues is largely dependent upon the period of circulatory arrest. To be sure, there is considerable variation in the tolerance of different tissues to ischemia, but in all of them limits exist as to the duration of circulatory arrest that will permit subsequent survival. Although these limits may be affected by a number of factors, including particularly development of collateral circulation as a result of the lesion itself, this cannot always be determined with sufficient reliability prior to operation. Accordingly, this aspect of the problem, namely, prevention of fatal ischemic damage to tissues during performance of the procedure, assumes major significance.

Two methods are available to overcome this problem. The first consists in the use of hypothermia to reduce oxygen demand by the tissues and the second in the use of a temporary shunt to conduct blood around the occluded segment with performance of the procedure in a manner to minimize the period of circulatory arrest. The former method was employed in the first case, but because it did not prove successful, the latter method was used in the subsequent three cases. The gratifying results obtained in these cases suggest that it is the preferable method, and for this reason its more detailed consideration seems desirable.

TECHNICAL CONSIDERATIONS

Because of the extensive nature of these aneurysms, involving both the lower thoracic and upper abdominal aorta, adequate exposure is essential. This may be satisfactorily obtained by a left thoracoabdominal approach. The patient is placed in the supine position with the left side of the chest slightly elevated and the left arm suspended from an overhead support (Fig. 11a). The incision is made over the left seventh or eighth rib, extending from the midaxillary line anteriorly and obliquely across the costal margin to the midabdominal line and then curving inferiorly as a midabdominal incision to a point well below the umbilicus (Fig. 11a). The left pleural and peritoneal cavities are entered, and after division of the costal cartilages, the diaphragm is incised radially from its peripheral attachment to the aortic hiatus, and the rib-spreader is inserted. This provides satisfactory exposure of the entire extent of the aneurysm as well as the aorta immediately above and below the lesion.

After adequate exploration to determine more precisely the extent and nature of the lesion, it is desirable to expose, by careful sharp and blunt dissection, the aorta immediately above and below the aneurysm and to encircle these segments of the aorta with umbilical tape as a safety measure for control of hemorrhage. The major visceral branches, such as the celiac, superior mesenteric and renal arteries arising from the aneurysm, are then similarly treated (Fig. 11b). In order to expose these vessels satisfactorily, as well as to permit subsequent excision of the aneurysm, a left retroperitoneal approach is employed. This is done by dividing the posterolateral parietal peritoneal attachment along its left border with mobilization of the visceral organs to the right side.

The shunt, which has previously been prepared, is then sutured into place by end-to-side anastomosis, with the use of partial tangential occlusion clamps, to the descending thoracic aorta immediately above the aneurysm and to the abdominal aorta just above the bifurcation (Fig. 11c). For this

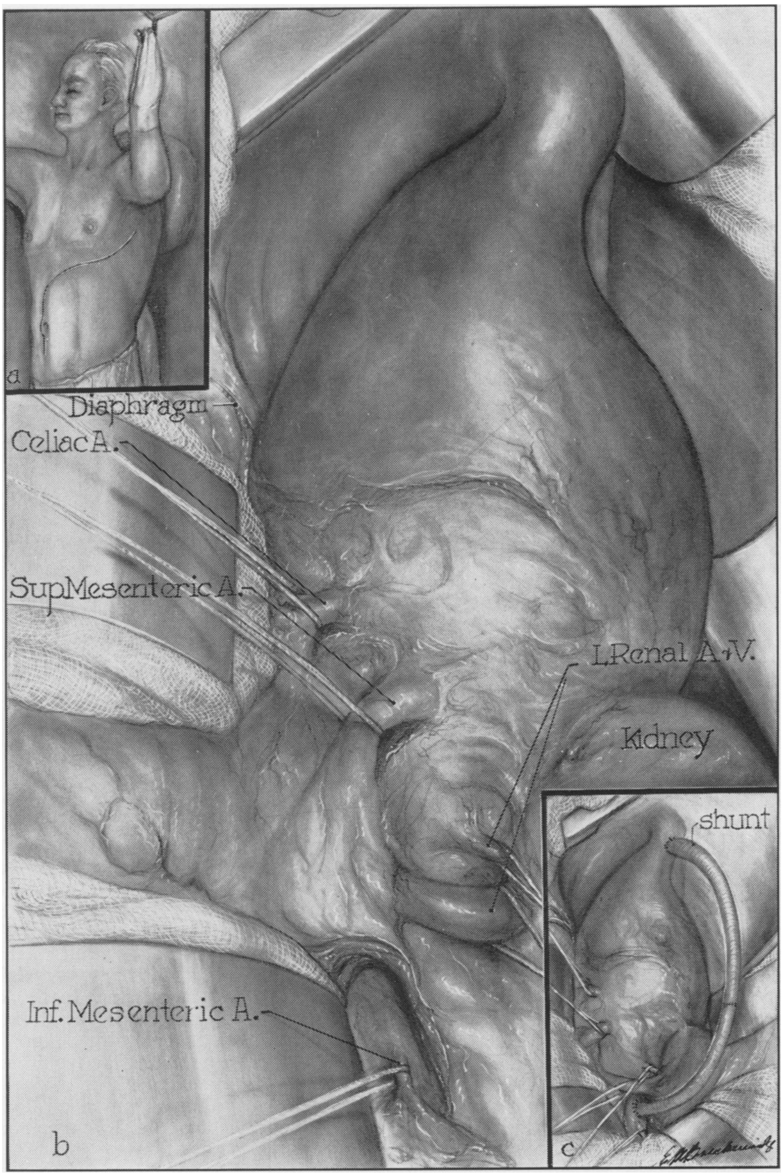

FIG. 11. Drawings made at operation in Case 2. (*a*) The patient is placed in the supine position with left shoulder slightly elevated and left arm supported overhead. Left thoracolumbar incision is employed. (*b*) The aorta above and below the aneurysm has been exposed and the celiac, superior mesenteric, and left renal arteries and the left renal vein have been isolated and tapes passed about them. The right renal artery lies behind the superior mesenteric artery and is not seen. (*c*) A shunt made of compressed polyvinyl sponge has been attached as an end-to-side anastomosis to the descending thoracic aorta above the aneurysm and to the abdominal aorta below the aneurysm.

purpose, it has been found desirable to use a shunt made of compressed polyvinyl sponge (Ivalon®) with a lumen 14 mm. in diameter [7, 8] (Fig. 10).

Once these steps have been completed and the shunt is functioning satisfactorily and conducting blood into the abdominal aorta below the aneurysm, attention may be directed toward mobilization and resection of the aneurysm. By careful sharp and blunt dissection, the aneurysm is freed from surrounding structures as well as possible,

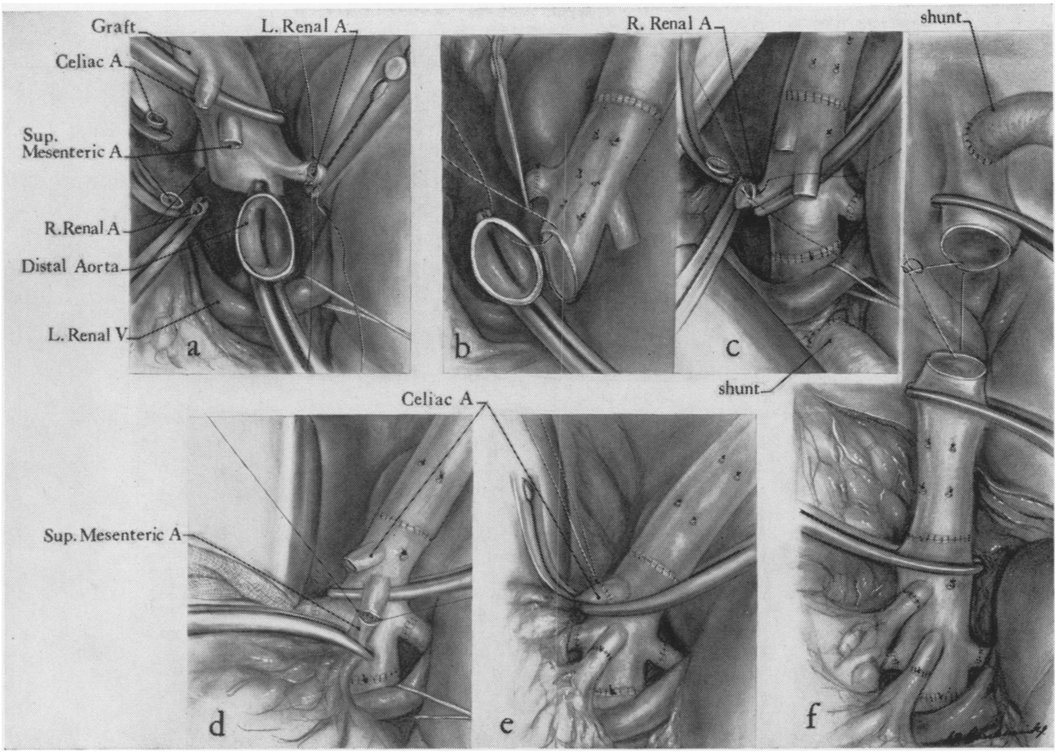

FIG. 12. (*a*) Anastomosis of the left renal artery to its comparable segment on the aortic homograft. The technic of anastomosis here as elsewhere consists in a continuous through-and-through suture of arterial silk. (*b*) Anastomosis of the distal end of the aortic homograft to the abdominal aorta. (*c*) With the anastomosis of the homograft to the left renal artery and to the abdominal aorta completed, an occluding clamp is applied to the graft in an oblique manner so that it lies below the origin of the right renal artery and above the origin of the left renal artery. The previously applied occluding clamp on the abdominal aorta has now been released, permitting restoration of blood flow to the left kidney through the shunt. The anastomosis to the right renal artery is then performed. (*d*) Anastomosis of the graft to the superior mesenteric artery. It may now be observed that the occluding clamp lies between the origin of the superior mesenteric and both renal arteries, thus permitting blood flow to be restored to both kidneys during the anastomosis of the superior mesenteric artery. (*e*) Anastomosis of the celiac artery. It may be noted again that the previously applied occluding clamp below the superior mesenteric artery has been moved up so as to lie immediately above it in order to permit restoration of blood flow through this vessel during the anastomosis of the celiac artery. (*f*) With the celiac artery anastomosis completed and the occluding clamp reapplied above it, blood flow has been restored to all the major visceral branches of the homograft during the completion of the final anastomosis to the descending thoracic aorta above.

following which special noncrushing arterial occlusion clamps are applied to the aorta immediately below the upper attachment of the shunt and immediately above its lower attachment, as well as to the celiac, superior mesenteric, and renal arteries. By this means circulation through the aneurysm is completely arrested, and it may be excised with minimal blood loss. In some instances it has not been feasible to free the aneurysm satisfactorily because of its intimate adherence to surrounding structures. Under these circumstances, as for example in Cases 1, 3, and 4, it may be preferable to apply the occluding clamps as already described and, after complete arrest of circulation through the aneurysm, it may be safely entered and removed by intramural dissection of the aneurysmal sac.

When the aneurysm has thus been excised, aortic continuity may be restored by means of a properly fitting abdominal aortic homograft, including the branches of the celiac, superior mesenteric, and renal

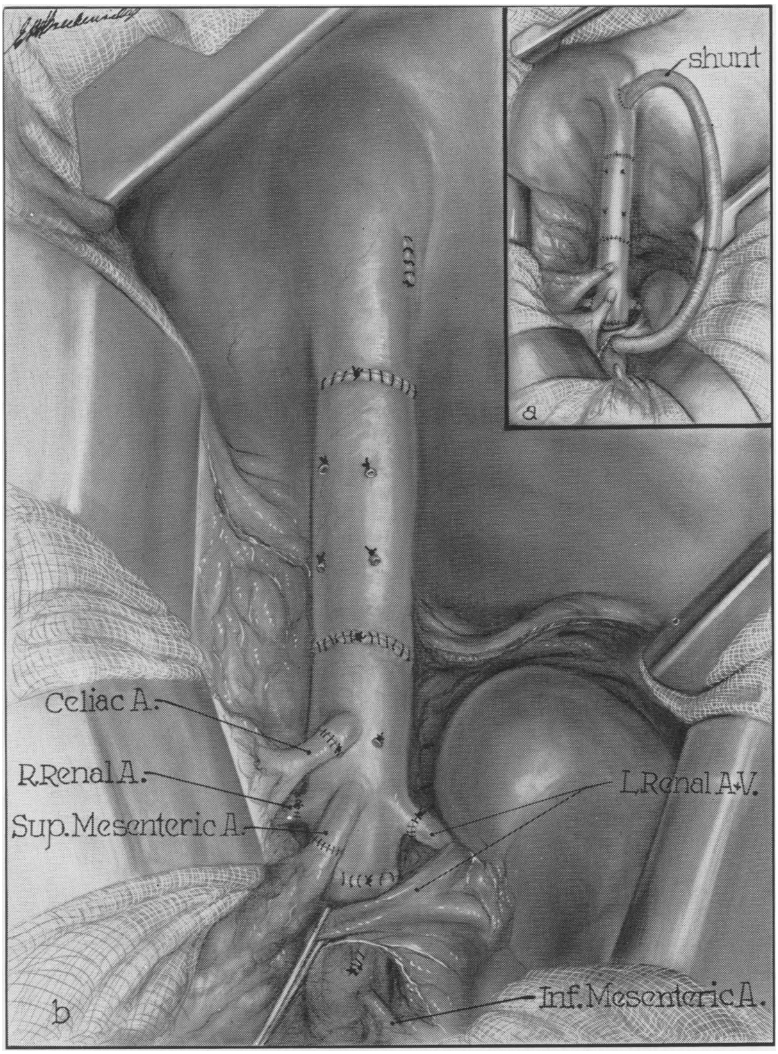

FIG. 13. Drawing showing completion of the homograft replacement in Case 2. (*a*) All anastomoses have been completed and blood flow through the aorta has been restored although the shunt is still in place. (*b*) The shunt has been removed and the openings in the aorta repaired.

arteries. In order to minimize the period of circulatory arrest to the abdominal organs, particularly the kidneys, which are considered more susceptible to ischemia, the anastomoses are performed in the following order. The left renal artery is attached first to its counterpart on the graft by end-to-end anastomosis, with the use of continuous through-and-through suture of 00000 arterial silk (Fig. 12a). Similar anastomosis is performed to unite the graft to the opening in the abdominal aorta (Fig. 12b). An occlusion clamp is applied to the graft somewhat obliquely so that it lies above the origin of the left renal artery but below the origin of the right renal artery, and the occluding clamp on the abdominal aorta immediately above the lower attachment of the shunt is released (Fig. 12c). This permits restoration of circulation into the left renal artery through the shunt. The anastomosis to the right renal artery is performed as previously described (Fig. 12c). Upon completion of this anastomosis, an occluding clamp is applied to the graft above the origin of both renal arteries but below the origin of the superior mesenteric artery, and the previously applied occluding clamp is released to permit blood flow into both renal arteries (Fig. 12d). In a similar manner, after the anastomosis to the superior mesenteric artery has been performed, the occluding clamp is moved above it while the anastomosis is performed to the celiac axis (Fig. 12e). After completing the latter anastomosis this maneuver with the occluding clamp is repeated, following which the final anastomosis is made between the graft and the opening in the lower thoracic aorta (Fig. 12f). In this manner circulation by way of the shunt is restored successively into each major visceral artery as rapidly as its anastomosis is performed. Following completion of the final anastomosis of the graft to the thoracic aorta, the occluding clamps at this level are removed and blood flow is restored in a normal manner through the graft (Fig. 13a). The shunt is then removed and the openings in the aorta are closed by a continuous suture of arterial silk (Fig. 13b). In cases in which the aneurysm has produced erosion of the vertebral bodies and a large excavated area, it is desirable to wrap the graft with a pedicled flap of omentum in order to provide it with a protecting bed of vascular tissue. The abdominal viscera are then replaced in their normal positions, and the posterolateral peritoneal attachments on the left side are approximated. The opening in the diaphragm is closed, and after a catheter has been placed in the left pleural space for underwater drainage, the wound is closed in layers.

PHYSIOLOGIC CONSIDERATIONS

The ischemic effects of temporary interruption of circulation to the major abdominal organs in man have not been clearly defined owing to the paucity of such observations. Moreover, studies directed toward this problem in animals have not yielded entirely satisfactory information. Thus, although the effects of ischemia on the kidney have been extensively investigated experimentally, variable results have been obtained depending to a large extent on the methods employed to produce renal ischemia as well as the type of animal used for this purpose. It has been demonstrated, for example, that occlusion of the renal artery for two hours in unilaterally nephrectomized rabbits uniformly produced death from renal damage.[1] On the other hand, in rats this procedure is apparently well tolerated, since most of the animals will survive this period of occlusion, but extension of this period beyond three hours reduces survival by about 50 per cent.[27, 28] In dogs longer periods of renal artery occlusion may also be tolerated with progressive increase in mortality after two hours.[16, 17, 25,40, 44] Although renal function is temporarily reduced during the early period, it gradually returns to normal over a period of two to three weeks. Similarly, autotransplantation of the kidney into the groin or neck, with complete interruption of its blood supply for periods up to two and one-half hours, results in severe temporary depression of renal function.[34] Renal homotransplants apparently behave in a similar fashion.[13, 14, 26] Dempster described a type of anuria that developed in 5 to 16 per cent of animals following autotransplantation and homotransplantation of kidneys. This anuria, which differs from the early depression of function customarily encountered, consists in complete failure to excrete urine after re-establishment of blood flow. It probably results from ischemia and arteriolar spasm incident to transplantation, since increased speed in removing and transplanting the kidney apparently decreases the incidence of this type of anuria.

The significance of the method of producing renal ischemia is well illustrated by experiments carried out in our laboratory.

Thus, two-hour occlusion of the aorta immediately above the renal arteries has a negligible effect on renal function in the dog.[31, 32] Similarly, unilateral renal artery occlusion for two hours is well tolerated, although it results in moderate depression of renal function in the occluded kidney but not in the contralateral kidney.[23, 31, 32, 39] On the other hand, simultaneous occlusion of the aorta and one renal artery for two hours results in severe depression of renal blood flow and glomerular filtration rate in the occluded kidney.[31, 32] Particularly significant is the fact that in this latter group of animals renal function in the kidney whose renal artery was not occluded remains unaffected, despite the fact that the aorta was occluded immediately above this point. It is also significant that the pressure in the aorta distal to the level of occlusion was found to be approximately 25 mm. Hg. These observations would suggest that this degree of subfiltration arterial pressure resulting from collateral blood flow provides a high degree of protection from ischemic damage to the kidney. These experiments were repeated utilizing hypothermia, and it was found that this afforded moderate protection to the kidney subjected to complete ischemia.[33]

Much less precise information is available on the ischemic effects of temporary arrest of circulation to the kidney in man.[9] Semb,[41] in performing segmental resection of the kidneys for tuberculosis, clamped the entire renal pedicle for one and one-half hours without significant alteration of renal function. Similarly, Bahnson[2, 3] reported survival of a patient following occlusion of both renal arteries for 37 minutes, although another of his patients died from renal failure after occlusion of the aorta above the renal arteries for 110 minutes. In the case recently reported by Ellis and associates,[21] occlusion of the aorta and one renal artery for 95 minutes produced no significant reduction in renal function. In describing the results of renal homotransplantation in nine patients, Hume and co-workers[26] reported resumption of function in kidneys that had been totally ischemic for 200 minutes. Similarly, Merrill and associates,[30] in performing homotransplantation of a healthy kidney from one identical twin to another, observed that total anoxia of the kidney for a period of 90 minutes does not mitigate against resumption of adequate function.

Thus, it is apparent from these experimental and clinical observations that considerable variations exist in the safe period of tolerance of the kidney to anoxia, ranging from less than one hour to over three hours. Obviously, there are a number of variables that influence this problem, including age, pre-existing renal disease, collateral blood supply, individual variations, and the like. In this connection it may be significant that three of the four patients reported herein were in the seventh decade. In these cases arrest of circulation to the kidneys for periods of less than one hour was well tolerated, but prolongation of this period for more than one and one-half hours, despite the use of hypothermia, resulted in fatal ischemic damage to the kidneys.

In the first case in which operation was performed under hypothermia complete renal ischemia bilaterally for 105 minutes resulted in acute, severe oliguria of 48 hours' duration, followed by gradual increase in urinary volume. However, in spite of the fact that urinary output had increased to 1,183 ml. on the fourth day after operation, glomerular filtration rate and renal blood flow were minimal and death from uremia occurred on the seventh postoperative day. Microscopically, there were extensive hyalin changes in the glomeruli and tubular necrosis. These events suggest that the fatal renal failure was a direct result of prolonged renal ischemia. If the patient could have survived the first week, perhaps renal recovery would have taken place, a possibility that is suggested by the experience with renal autotransplants.[13, 14, 34]

In the second case blood flow to the right and left kidneys was interrupted for 27 and 23 minutes, respectively (Chart III). The pattern of recovery was similar to that observed in acute renal failure from other causes and consisted of early oliguria followed by diuresis with return to normal function about the third week. Discrete renal function studies in this case point to ischemic involvement of the entire nephron initially with glomerular recovery preceding tubular recovery (Chart I).

Renal response in the third case was strikingly similar to that in the second case although the right kidney was ischemic for only 15 minutes, while the left was ischemic for 43 minutes. In this instance the occurrence of pronounced diuresis suggested more extensive tubular involvement. Nonetheless, recovery was practically complete by the end of the third week. The response in the fourth case was somewhat similar, although as might be anticipated from the unilateral ischemia, depression of renal function was only moderate and recovery was more rapid than in the other cases.

These limited observations do not permit definite conclusions to be drawn regarding the maximum safe period of complete renal ischemia. They do, however, point to the importance of minimizing this period. It seems reasonable to state that in cases of this kind periods up to 45 minutes may be safely tolerated, but extension beyond this time is increasingly hazardous. It would also appear that hypothermia of moderate degree, i.e., with reduction of body temperature to 32.2° C. (90° F.), cannot be relied upon to provide adequate protection against fatal ischemic damage to the kidneys when the period of ischemia extends over 100 minutes.

Whereas observations on the effects of renal ischemia in man are relatively few, there are even fewer data pertaining to the effects of ischemia on the liver and gastro-intestinal tract. There are a number of older reports of ligation of the thoracic aorta for aneurysm and considerable recent experience with temporary occlusion for resection of aneurysms,[10-12] but these are not pertinent since only partial ischemia of these structures is produced in this way. Nor are the observations following celiac or hepatic artery ligation for bleeding esophageal varices relevant, since an extensive collateral network is still functioning.

The tolerance of the liver to ischemia has been extensively investigated in experimental animals, but the results of these studies have been quite variable.[4-6, 15, 18-20, 24, 29, 35, 36, 38, 43] According to these experiments, for example, the maximum safe period of arrest of circulation to the liver varies from somewhat less than one half hour to a little more than one hour. These variations in results are apparently due to a number of factors, including particularly the different species of experimental animals used, the different methods of producing arrest of hepatic circulation with consequent differences in the degree of completeness of occluding the afferent hepatic circulation, the presence of anomalous or accessory arteries to the liver, and the administration of antimicrobial agents. For these reasons it is difficult to evaluate these experimental observations in determining more precisely the critical period of hepatic anoxia. The weight of evidence would suggest, however, that this period closely approaches one half hour. There is also some experimental evidence to suggest that this period may be prolonged to one hour by the use of hypothermia.[5, 37, 42]

This problem in man is even less well defined owing to the paucity of such observations. Wangensteen[45] reported performance of left hepatic lobectomy in three cases with simultaneous occlusion of the hepatic, gastroduodenal, and superior mesenteric arteries and the portal vein. In the two patients who survived operation the periods of ischemia were 33 and 24 minutes respectively, whereas in the patient who died there were two periods of ischemia of 12 and 15 minutes each interrupted by a 20-minute period of release of ischemia. Two somewhat similar cases of left hepatic lobectomy for metastatic carcinoma have also been reported by Burch, Traphagen, and Folkman.[4] In their first patient who recovered, the aorta above the celiac axis and the portal vein were occluded for 10 minutes with no apparent disturbance in liver function. Similar occlusion for the same period of time was done in the second case, but the patient developed extensive mesenteric thrombosis which subsequently caused his death. More recently, Shumway and Lewis [42] reported four cases of right hepatic lobectomy performed under hypothermia in which temporary arrest of hepatic circulation was produced by occlusion of the thoracic aorta at the level of the tenth intercostal space, the inferior vena cava above and below the liver, the hepatic artery, and the portal vein. In the two patients who survived operation the period of ischemia was 45 minutes, while in the other two patients who died it was 33 and 40 minutes, respectively.

The four cases reported herein afforded a unique opportunity to observe the effects of relatively complete interruption of arterial blood supply to the liver and gastrointestinal tract. Thus, with the aorta occluded above the diaphragm and below the renal arteries, and with celiac and superior mesenteric arteries interrupted, the liver was nourished only by the portal venous flow. The effectiveness of this afferent nutrient vessel to the liver was also greatly diminished through reduction of arterial blood flow to the portal bed since this was derived primarily from the inferior mesenteric artery. In the three successful cases the periods of hepatic ischemia ranged from 44 to 116 minutes. Yet in no instance was hepatic function seriously deranged (Chart II). It cannot be stated with certainty that hypothermia was responsible for the apparent tolerance of the liver to ischemia of two hours in the first case, since the patient survived only one week. There was no evidence, however, during this time nor at autopsy of significant liver derangement. The most consistent changes were noted in serum bilirubin levels and in the cephalin flocculation. In view of the large amount of whole blood administered during operation, however, the slight increase in serum bilirubin does not appear to be significant. Accordingly, these observations would suggest that in man the liver can tolerate occlusion of its major arterial blood supply for relatively long periods, almost two hours, without significant alteration in function.

In the first case arterial blood flow to the entire gastro-intestinal tract was interrupted for 105 minutes. Postoperatively, there were moderately severe intestinal distention and diarrhea suggesting some disturbances but otherwise no evidence of serious ischemic damage to these organs. In the remaining cases the superior mesenteric artery was occluded for periods ranging from 36 to 102 minutes, but a temporary aortic shunt maintained blood flow through the inferior mesenteric artery so that the gastro-intestinal tract was not completely ischemic. In none of these cases was intestinal distention or diarrhea a problem, and resumption of gastro-intestinal function took place in a normal manner following operation.

SUMMARY

1. Four cases of extensive thoracoabdominal aneurysm of the aorta treated by resection and homograft replacement are reported. In all of these cases the aneurysm extended from the lower descending thoracic aorta to the lower abdominal aorta and involved the celiac, superior mesenteric, and one or both renal arteries. The

operative procedure consisted in excision of the aneurysm and replacement with an aortic homograft with restoration of continuity to the celiac axis and superior mesenteric arteries in all as well as to both renal arteries in two and to one of the renal arteries in the other two cases.

2. The most important consideration in extirpation of aneurysms of this type arises from the potential ischemic damage to such vital organs as the kidneys, liver, and gastro-intestinal tract as a consequence of temporary arrest of circulation to them during performance of the procedure. Two methods are available to overcome this problem, namely hypothermia and the use of a temporary shunt to conduct blood around the occluded segment with the performance of the procedure in a manner to minimize the period of circulatory arrest.

3. Hypothermia was used in the first case, but the patient died of renal failure one week after operation. The superior mesenteric and both renal arteries were occluded for 105 minutes and the celiac artery for 120 minutes.

4. In the other three cases temporary shunts were employed permitting significant reduction in the period of temporary arrest of circulation to the abdominal viscera. The successful results obtained in these cases emphasize the importance of performing the procedure in such a manner as to minimize the period of ischemia to these vital structures.

5. In the three successful cases the period of occlusion of the renal arteries ranged from 15 to 46 minutes. Serial renal function studies in these cases revealed a characteristic pattern of depression of function, as reflected by increase in the blood urea nitrogen level and significant reduction in renal blood flow and glomerular filtration rate, during the first four or five days after operation with progressive return to normal during the subsequent ten days to two weeks.

6. The period of occlusion of the celiac artery in these cases ranged from 44 to 116 minutes. Studies of hepatic function revealed no significant alterations.

7. The period of arrest of circulation through the superior mesenteric artery varied from 36 to 102 minutes and no significant disturbances in gastro-intestinal function were observed.

BIBLIOGRAPHY

1. Badenoch, A. W. and E. M. Darmady: The Effects of Temporary Occlusion of the Renal Artery in Rabbits and its Relationship to Traumatic Uraemia. J. Path. and Bact., **59**: 79, 1947.
2. Bahnson, H. T.: Definitive Treatment of Saccular Aneurysms of the Aorta with Excision of Sac and Aortic Suture. Surg., Gynec. and Obst., **96**: 383, 1953.
3. Bahnson, H. T.: Treatment of Abdominal Aortic Aneurysm by Excision and Replacement by Homograft. Circulation, **9**: 494, 1954.
4. Burch, B. H., D. W. Traphagen and M. J. Folkman: The Use of Aortic Occlusion in Abdominal Surgery with a Report of Two Human Cases. Surgery, **34**: 672, Oct. 1953.
5. Burch, B. H., D. W. Traphagen, M. J. Folkman, D. A. Rosenbaum and E. C. Mueller: Temporary Aortic Occlusion in Abdminal Surgery. Surgery, **35**: 684, May 1954.
6. Child, C. G., III, R. D. McClure, Jr. and D. M. Hays: Studies on Hepatic Circulation in Macaca Mulatta Monkey and in Man. Surg. Forum, American College of Surgeons, p. 140, 1952.
7. Cooley, D. A., D. E. Mahaffey and M. E. DeBakey: Total Excision of the Aortic Arch for Aneurysm. Surg., Gynec., & Obst., **101**: 667, Dec. 1955.
8. Creech, O., Jr., M. E. DeBakey and D. E. Mahaffey: Total Resection of the Aortic Arch. Surgery (In press).
9. Creech, O., Jr., M. E. DeBakey, G. C. Morris, Jr. and J. H. Moyer: Experimental and Clinical Observations on the Effects of Renal Ischemia. Surgery, **40**: 129, July 1956.
10. DeBakey, M. E., D. A. Cooley and O. Creech, Jr.: Resection of the Aorta for Aneurysms and Occlusive Disease with Particular Reference to the Use of Hypothermia. Analysis of 240 Cases. Trans. Amer. Coll. Cardiology, **5**: 153, 1955.

11. DeBakey, M. E., D. A. Cooley and O. Creech, Jr.: Resection of Aneurysms of the Thoracic Aorta. Surg. Clin. N. America, W. B. Saunders Co., Philadelphia. Aug. 1956, pp. 969–982.
12. DeBakey, M. E., G. C. Morris, Jr. and J. H. Moyer: Unpublished data.
13. Dempster, W. J.: The Anurias Following Kidney Transplantation. Acta med. scandinav., **148**: 91, 1954.
14. Dempster, W. J. and A. M. Joekes: Functional Studies of the Kidney Autotransplanted to the Neck of Dogs. Acta med. scandinav., **147**: 99, 1953.
15. DeWeese, M. S. and C. Lewis: Partial Hepatectomy in the Dog. Surgery, **30**: 642, 1951.
16. Donnet, V., S. Maffre and A. Pruneyre: Evolution de la Diurese Après Occlusion Temporaire ou Prolongée d'une Artère Rénal chez le Chien non Narcosé. J. Physiol., **43**: 715, 1951.
17. Donnet, V. and A. Pruneyre: Rétablissement des Fonctions du Vein Soumis à une Anémie Expérimentale Prolongée. Compt. rend. Soc. biol., **147**: 442, 1953.
18. Drapanas, T., D. R. Becker, G. S. Alfano, W. H. Potter and J. D. Stewart: Some Effects of Interrupting Hepatic Blood Flow. Ann. Surg., **142**: 831, Nov. 1955.
19. Duchinova, S. L.: Ueber temporäre Abklemmung des Lig. Hepato-Duodenale für blutlose Operatione an der Leber. Zentralorg. f. d. ges. Chir., **35**: 581–582, 1925.
20. Edwards, W. S., O. K. Tidwell and C. R. Lombardo: The Mechanism of Death from Thoracic Aortic Occlusion. Surg. Forum, American College of Surgeons, p. 90, 1954.
21. Ellis, F. H., Jr., R. A. Helden and E. A. Hines, Jr.: Aneurysm of the Abdominal Aorta Involving the Right Renal Artery. Ann. Surg., **142**: 992, 1955.
22. Etheredge, S. N., J. Yee, J. V. Smith, S. Schonberger and M. J. Goldman: Successful Resection of a Large Aneurysm of the Upper Abdominal Aorta and Replacement with Homograft. Surgery, **38**: 1071, Dec. 1955.
23. Friedman, S. M., R. L. Johnson and C. L. Friedman: The Pattern of Recovery of Renal Function Following Renal Artery Occlusion in the Dog. Circulation Res., **2**: 231, 1954.
24. Goodrich, E. O., Jr., H. F. Welch, J. A. Nelson, T. S. Beecher and C. S. Welch: Homotransplantation of the Canine Liver. Surgery, **39**: 244, Feb. 1956.
25. Hamilton, P. B., R. A. Phillips and A. Hiller: Duration of Renal Ischemia Required to Produce Uremia. Am. J. Physiol., **152**: 517, 1948.
26. Hume, D. M., J. P. Merrill, B. F. Miller and G. W. Thorn: Experiences with Renal Homotransplantation in the Human: Report of Nine Cases. J. Clin. Invest., **34**: 327, Feb. 1955.
27. Koletsky, S.: Effects of Temporary Interruption of Renal Circulation in Rats. Arch. Path., **58**: 592, 1954.
28. Koletsky, S. and B. J. Dillan: Survival of Rats after Temporary Complete Renal Ischemia. Proc. Soc. Exper. Biol. & Med., **70**: 14, 1949.
29. Markowitz, J., A. Rappaport and A. C. Scott: Prevention of Liver Necrosis Following Ligation of the Hepatic Artery. Proc. Soc. Exper. Biol. and Med., **70**: 305, 1949.
30. Merrill, J. P., J. E. Murray, J. H. Harrison and W. R. Guild: Successful Homotransplantation of the Human Kidney Between Identical Twins. J. A. M. A., **160**: 277, Jan. 28, 1956.
31. Morris, G. C., Jr., C. F. Heider and J. H. Moyer: The Protective Effect of Subfiltration Arterial Pressure on the Kidney. Surg. Forum, American College of Surgeons, p. 623, 1956.
32. Morris, G. C., Jr., C. F. Heider, J. H. Moyer and C. Handley: The Effect of Various Types of Renal Ischemia on Renal Function. Clin. Res. Proceedings, **4**: 42, 1956.
33. Moyer, J. H., G. C. Morris, Jr. and M. E. DeBakey: Renal Functional Response to Hypothermia and Ischemia in Man and Dog. National Research Council, Conference on the Physiology of Induced Hypothermia, Oct. 28–29, 1955, Washington, D. C.
34. Murray, G. and R. Holden: Transplantation of Kidneys, Experimentally and in Human Cases. Am. J. Surg., **87**: 508, April 1954.
35. Popper, H. L., N. C. Jefferson and H. Necheles: Survival of Dogs After Partial or Total Devascularization of the Liver. Ann. Surg., **140**: 93, 1954.
36. Raffucci, F. L.: The Effects of Temporary Occlusion of the Afferent Hepatic Circulation in Dogs. Surgery, **33**: 342, March 1953.
37. Raffucci, F. L., F. J. Lewis and O. H. Wangensteen: Hypothermia in Experimental Hepatic Surgery. Proc. Soc. Exper. Biol. & Med., **83**: 639, 1953.
38. Rappaport, A. M., W. N. Lotto and W. M. Lougheed: Experimental Hepatic Ischemia; Collateral Circulation of the Liver. Ann. Surg., **140**: 695, 1954.
39. Roof, B. S., H. D. Lauson, S. T. Bella and H. A. Eder: Recovery of Glomerular and Tubular Function, Including P-aminohip-

purate Extraction, Following Two Hours of Renal Artery Occlusion in the Dog. Am. J. Physiol., **166**: 666, 1951.

40. Scheibe, J. R., E. Giraldi and C. W. Vermeulen: The Effect of Temporary Renal Vascular Occlusion on Kidney Function. Surgery, **25**: 724, 1949.
41. Semb, C.: Renal Tuberculosis and its Treatment by Partial Resection of the Kidney. Acta chir. scandinav., **98**: 457, 1949.
42. Shumway, N. E. and F. J. Lewis: Hypothermia and Temporary Occlusion of the Hepatic Circulation. National Research Council, Conference on the Physiology of Induced Hypothermia, Oct. 28–29, 1955, Washington, D. C.
43. Tinker, M. B. and M. B. Tinker, Jr.: Resection of the Liver. J. A. M. A., **112**: 2006, 1939.
44. Van Slyke, D. D., R. A. Phillips, P. B. Hamilton, R. M. Archibald, V. P. Dole and K. Emerson, Jr.: Effect of Shock on the Kidney. Tr. A. Am. Physicians, **58**: 119, 1944.
45. Wangensteen, O. H.: Discussion of paper by Ravdin and Vars: Further Studies on Factors Influencing Liver Injury and Liver Repair. Ann. Surg., **132**: 362, 1950.

DISCUSSION.—DR. JOHN H. GIBBON, JR., Philadelphia, Pennsylvania: I make no apology for getting up a third time this afternoon to pay tribute to one of America's and one of the world's greatest surgeons. We have not only heard a description of one of the most brilliant technical achievements that to my knowledge has been accomplished in the last few years in the field of vascular surgery, but we have also heard a presentation by a man who is extraordinarily modest about his achievements, and who not only in the technical field but in the field of devotion to the interests of surgeons and surgery at large, and surgical education, has had an extraordinary career. I think this Association should take note of the tremendous achievements of this man. I believe we have a right to be proud of him as a member of this Association. (Applause)

DR. HENRY T. BAHNSON, Baltimore, Maryland: To hear a monumental and simply thrilling feat in surgical treatment emanating from Houston is certainly not unusual and hardly remarkable. This afternoon is no exception. I am sure Dr. Dean Warren and I are delighted to serve as appetizers for this entree. (Laughter)

For those of you who, like myself, perhaps are not quite so skillful, I think it should be mentioned, and certainly not to detract from this work, that many of these aneurysms that are located in this area anse posteriorly. In many instances they do not involve the mouths of the visceral vessels. In two cases that we have seen in a much smaller group of patients, one was able to clamp the aorta above and below and to perform a posterolateral aortorraphy. It requires a much shorter time, and I believe is less risky, although admittedly the end result may not be as good as the procedure Dr. DeBakey has described.

PRESIDENT BLALOCK: I would like to say a word about a great man. One is now approaching the rostrum.

DR. ARTHUR H. BLAKEMORE, New York, New York: I was very embarrassed in New York just a short time before I left. A 79-year-old gentleman arrived at 5:30 a.m. from Binghamton, with a supposedly ruptured aneurysm of the abdominal aorta. Fortunately, the patient was in good condition upon arrival and at operation the aneurysm was found not to be ruptured; apparently the rapid development of a secondary sacculation of the aneurysm had been the cause of severe pain immediately following the act of shoveling water in a flooded cellar. Whereas there was no blood to be seen surrounding the aneurysm, there was marked inflammatory edema of the surrounding tissues and aneurysm wall. The latter was necrotic in places. A finding of great concern and considerable embarrassment at the time in this patient was involvement of the entire abdominal aorta by aneurysm. The secondary sacculation, starting immediately distal to the renal arteries, expanded rapidly to a maximum diameter of 15 centimeters, but fortunately contracted nearing the bifurcation level finally to a diameter approximating 6 centimenters. Whereas proximal to the renal arteries, upward to the diaphragm, the aneurysm ranged from 7 to 9 centimeters in diameter.

The aneurysm had the characteristic appearance of the arteriosclerotic variety. The patient's systolic blood pressure ranged from 170–200 mm. Hg, and diastolic from 95–105 mm. Hg. It was realized at operation that rupture of the aneurysm sacculation below the renal arteries was imminent. Fortunately, a line of section relatively free of sclerotic plaques could be made distal to the renal arteries. The difficulty was the apparent diameter at this level approximated 9 centimeters, compared to approximately a diameter of 6 centimeters at the bifurcation. Encouragement to try resection of the aneurysm at the above levels was forthcoming when Doctor Arthur Voorhees produced a braided tube of orlon measuring 4 centimeters in diameter, the largest diameter that was leakproof to blood that the present braiding machine will fabricate. As it worked out, the proximal and distal diameters shrank a centimeter or two following resection of the aneurysm, and the ends of the braided tube dilated to accommodate the suture