PROGRESSIVE CONSTRICTIVE OCCLUSION OF THE ABDOMINAL AORTA WITH WIRING AND ELECTROTHERMIC COAGULATION

A ONE-STAGE OPERATION FOR ARTERIOSCLEROTIC ANEURYSMS OF THE ABDOMINAL AORTA*

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IN 1938 AN ELECTROTHERMIC METHOD of inactivating aneurysms by coagulation was reported by us.[1] The method embraces the employment of fine (No. 34 gauge B & S), insulated, coin silver wire as follows: Five meters of wire are wound on each of two aluminum spools. The center of the ten-meter segment is bent into a loop for passage through a special needle into the aneurysm; this permits the establishment of electrical contact with the protruding ends of the wire.

A source of approximately 100 volts of ungrounded, direct current is used for the heating apparatus. The current is so regulated (Fig. 1) and calibrated against changes in the electrical resistance of the wire upon heating as to show an accurate measurement of the average temperature of the wire at all times, and of the rate of blood flow through the aneurysm upon initial heating. Each ten-meter segment of wire is heated to an average temperature of 80°C. for a ten-second period, following which the ends of the wire are buried within the sac. This heating of the wire above the heat coagulation point of the blood proteins results in the deposit upon the wire of a tenacious, clot stimulating, protein coagulum.

The method has proved highly efficient in inactivating aneurysms of the saccular type, and of equal importance, affords a means of controlled, concentric clotting for aneurysms of the fusiform type.[2, 3] The protective feature of controlled differential clotting by the electrothermic method permitted us to safely broaden our experience in the treatment of fusiform aneurysm of the aorta, knowing that inadvertent closure of this great vessel would be calamitous.

Relating controlled, differential clotting by the electrothermic method to rate of blood flow is best illustrated by citing a case of fusiform, syphilitic aneurysm of the abdominal aorta in a 32-year-old Negro. This man was known to have a pulsating mass, with pain in the epigastrium of one and a half years' duration. Roentgen rays demonstrated erosion of the anterior surfaces of the twelfth dorsal, first and second lumbar vertebrae. Examiination of the aneurysm at operation revealed it to be of the fusiform type, arising from the aorta just above the origin of the superior mesenteric artery and extending down the aorta well below the origin of the renal arteries (Fig. 2).

The problem in this case was to inactivate the aneurysm without curtailing renal blood flow. The man was operated upon employing the wiring and electrothermic method in two stages, one month apart (September 17 and October 20, 1938). How well the aneurysm has been inactivated and the arterial blood flow to the kidneys preserved is demonstrated by a recent aortogram made March 22, 1950, just 11 years and five months following operation. At the first operation two ten-meter segments (66 feet) of wire were introduced into the fusiform aneurysm, and the greater

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part of the second segment of wire was concentrated in the lower pole of the aneurysm. Each segment of wire was heated to an average temperature of 80°C. for a ten-second period. Following the first stage operation the aneurysm became more firm and pulsated less. Pulsations were markedly reduced in the femoral arteries, resulting in a fall of eight divisions below the preoperative oscillometric readings. The patient's pain disappeared following operation, never to return.

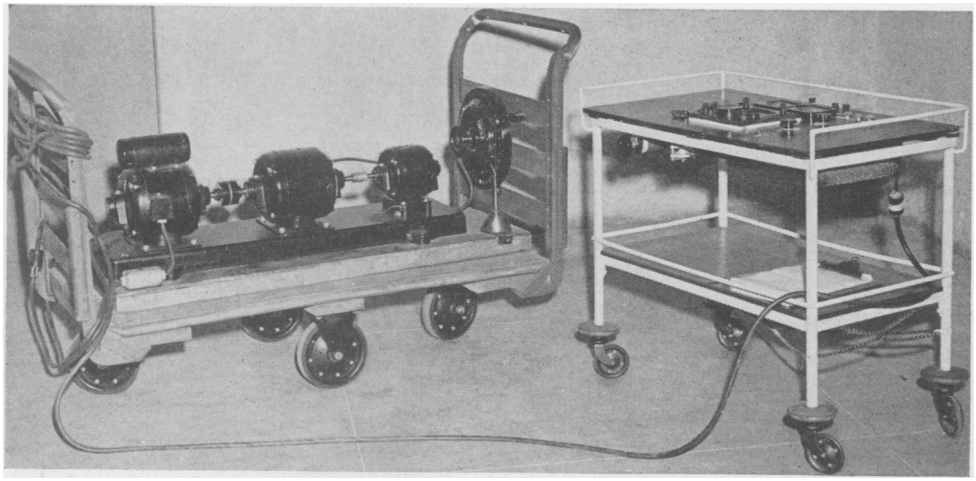


FIG. 1.—This shows the electrical equipment employed in electrothermic coagulation of aneurysms. The equipment used to convert AC current to ungrounded DC current is illustrated on the left. Mounted on the portable table is an ohmmeter, ammeter, voltmeter, and ratiometer. The latter is calibrated to show the average temperature of wire imbedded within an aneurysm during heating.

After the elapse of a month a second stage wiring was done. At this operation the wire was concentrated in the distal pole of the aneurysm to produce progressive endo-arterial occlusion. Again, two ten-meter segments (66 feet) of wire were introduced and each segment heated to an average temperature of 80°C. for a ten-second period. Following this operation pulsations could no longer be felt in the femoral arteries and the oscillometric readings from the upper one-third of the legs fell from a former level of one division to only a half of a division. Though sustained readings of a half division was proof of patency of the aorta, it must be remembered that this operation was performed before the days of anticoagulants. As further proof of maintained patency of this aorta at the time, the patient promptly returned to his job as a Pullman waiter, and the only semblance of circulatory inadequacy was some tiredness in the legs upon running. During the ensuing months, *pari passu* with the development of collateral circulation, the patient's aorta, below the origin of the renal arteries, must have become closed off completely. At any rate, such was the case two and a half years following operation, when an aortogram was made.

The above case is cited in some detail for the following reasons: (1) The patient is alive and working, symptom free. He has gained 52 lbs. since operation, and now 11 years and five months since operation there has been no roentgen ray or other evidence of growth of the aneurysm. Statistically speaking, without operation, his life expectancy was but 18 months. (2) This aneurysm of the aorta, fusiform in shape, whose sac encompasses both renal arteries, pre-

sented a supreme test for a method of wiring aneurysms. To have employed a method which did not guarantee control of blood clotting would but have courted disaster in such a case.

In the electrothermic method, unlike other methods of wiring aneurysms, clot stimulation is controlled by differential rate of blood flow. This ability to measure rate of blood flow, employing the electrothermic (hot wire) method, for the first time places the coagulation of aneurysms on a sound, scientific basis. It was recognized early in our experience that the rate of blood flow in saccular aneurysms of identical size may vary as much as 300 per cent, depending upon the size of the opening into the sac. The high rate of blood flow prevailing in saccular aneurysms with wide mouths approaches that of the high velocity fusiform type. Furthermore, in relating rate of blood flow to the occurrence of mass clotting within aneurysms, additional experience revealed that a wide mouth, high velocity aneurysm may require as much as three to four times the number of feet of wire for its impedance effect upon blood flow as does an aneurysm of equal size but having a small opening into the sac.

In view of the above facts, when employing the electrothermic method it is possible to determine, on the basis of the number of amperes required to heat to 80°C. the first ten-meter segment of wife, (1) the variety of aneurysm (based upon rate of flow), and (2) approximately the number of segments of wire that will be required to impede blood flow to the point of occurrence of sudden mass clotting; namely, the requirement of 3 amperes, the current necessary to heat a final ten-meter segment of wire to 80°C.

Heating a ten-meter segment of wire to an *average* temperature of 80°C. for a ten-second period affords a means of control of the distribution and extent of blood clotting on the basis of differential rate of blood flow. This is by virtue of the fact that only the wire within the recesses of the aneurysm become sufficiently hot to result in the deposit of a clot stimulating protein coagulum. That portion of the segment of wire which may have crossed the fast-moving blood current of the aorta is cooled so rapidly that it remains uncoated with protein coagulum and therefore fails to stimulate blood clotting where it is not wanted. It is this fortunate feature, peculiar to the electrothermic method, which makes the process of clotting a controlled one, ideally suited to the treatment of fusiform aneu-

FIG. 2.—This shows an aortogram of a syphilitic aneurysm of the abdominal aorta treated by wiring, electrothermic coagulation with progressive endo-arterial occlusion. Note arrows marking the outer border of the wire which delineates a large fusiform aneurysm. The opacified blood demonstrates the patency of the renal arteries which arise near the mid-section of the aneurysm. In the upper portion of the aneurysm note the arrows outlining the outer border of the aneurysm, and note the distance inward to the opacified blood column in the center. This is the area and extent of concentric clotting. The width of the aneurysm in the above section has not changed in the 11 years and five months since operation. The total absence of opacified blood in the aneurysm below the level of the renal arteries shows the area of complete endo-arterial occlusion. Finally, observe the presence of collateral vessels.

rysms without the hazard of unwittingly closing off the parent artery. In fusiform aneurysms the rate of blood flow is fast through the center and slowest along the sac wall. This disposes to concentric clotting. Thus with the introduction and heating of additional segments of wire concentric clotting is built in towards the center. In this manner the space for blood flow may be progressively reduced to the diameter of the parent artery. Or, if carried one step further, the method is adaptable for safe, progressive, endo-arterial occlusion *pari passu* with the development of collateral circulation.

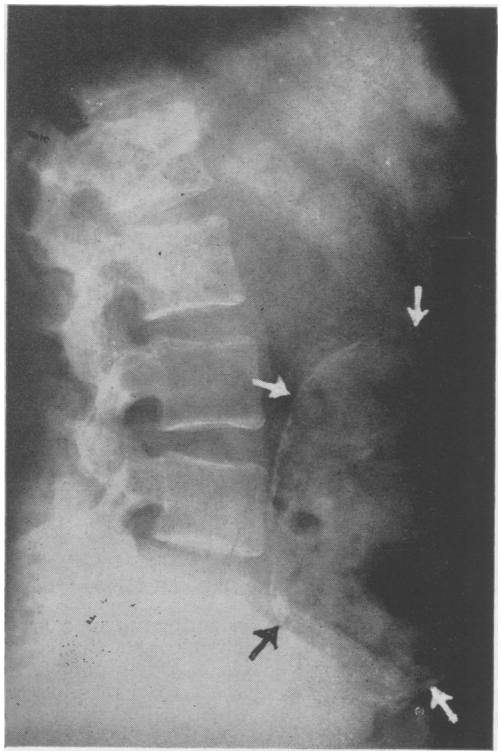


FIG. 3.—Lateral roentgen ray of the abdomen showing a very large arteriosclerotic aneurysm of the abdominal aorta. Arrows mark the outline of the aneurysm. Note that the calcific wall does not impinge upon the anterior border of the fifth lumbar vertebra.

The great practical importance of the above described special features of the electrothermic method of wiring aneurysms are splendidly illustrated by the case previously cited. The aortogram (Fig. 2) offers corroborative evidence as follows, starting with the top of the aneurysm and working downward: (1) Note the presence and extent of concentric clotting in the fusiform sac extending down practically to the level of origin of the renal arteries. This is indicated by the distance from the outer margins of the wire (see arrows) inward to the margin of the opacified blood column. (2) The preservation of normal arterial blood flow to both kidneys is demonstrated. (3) Immediately below this renal artery level, note complete clotting of the rest of the fusiform aneurysm with diversion of aortic blood flow into collateral arteries.

The aortogram in this case presents a composite picture of the extreme versatility of the electrothermic method in selective clotting based upon differential rate of blood flow. In that portion of the aneurysm distal to the renal arteries, by concentration of wire for its impedance effect, progressive endo-arterial occlusion was achieved *pari passu* with the development of collateral circulation. If one studies this aortogram carefully and fully appreciates what has been accomplished one is not surprised that this man is alive, working, and symptom free, 11 years and five months after operation. The method has fulfilled all the requirements for cure that past experience has dictated.

The electrothermic method of wiring aneurysms has repeatedly proved its worth as a safe method of controlled clotting for progressive endo-arterial occlusion in the treatment of aneurysms of the aorta arising distal to the renal arteries and aneurysms of the innominate and peripheral arteries. Not only has the method proved successful in the treatment of syphilitic aneurysms but has been used with outstanding success in aged patients having aneurysms of the arteriosclerotic variety.

In recent years attention has been called to the growing importance of arteriosclo-

rotic aneurysm of the abdominal aorta and their clinical behavior.[5, 6] Not only are we seeing more of these cases but they are occurring at an age (average 60 years) at which people do not expect to die these days. And yet recently, within the span of one 12-months' period, as many as 22 cases of ruptured arteriosclerotic aneurysms came to our attention from the Greater New York area alone.

There are several important reasons why cases of arteriosclerotic aneurysms of the abdominal aorta are so often brought to our attention only as dire emergencies. One of these reasons has to do with the inherent pathology of the disease and we, as a profession, can do little about it. I refer to the frequent absence of pain in these cases until the aneurysm has progressed to the point of rupture or imminent rupture. Since pain is the one most important symptom that makes people seek medical relief, there will always be a certain number of cases that will present themselves as dire emergencies.

We have been long interested in the correlation of pain with the pathologic changes and other special features of the arteriosclerotic aneurysm of the abdominal aorta.[4, 5] This clinical-pathologic study has been sufficiently extensive to bring out certain important facts. In the first place it has not been sufficiently emphasized that arteriosclerotic aneurysms of the abdominal aorta do not cause erosion of the vertebrae. Vertebral erosion, as all know, is often an early cause of pain in syphilitic aneurysm. That arteriosclerotic aneurysms of the abdominal aorta may reach a large size without even making contact with the vertebral bodies is well illustrated by Figure 3. This roentgenogram made in the lateral position shows well, by the calcific outline of the aneurysm sac wall, how far forward the aneurysm really is.

We have come to the conclusion after examining many arteriosclerotic aneurysms that the most reasonable explanation for the absence of vertebral erosion is the fact that the aorta in its elongated, arteriosclerotic condition angulates far forward, to the left and sometimes to the right immediately below its escape through the hiatus of the diaphragm. Furthermore, the arteriosclerotic aneurysm of the abdominal aorta is invariably fusiform in type. These characteristic manifestations account for the absence of bone erosion.

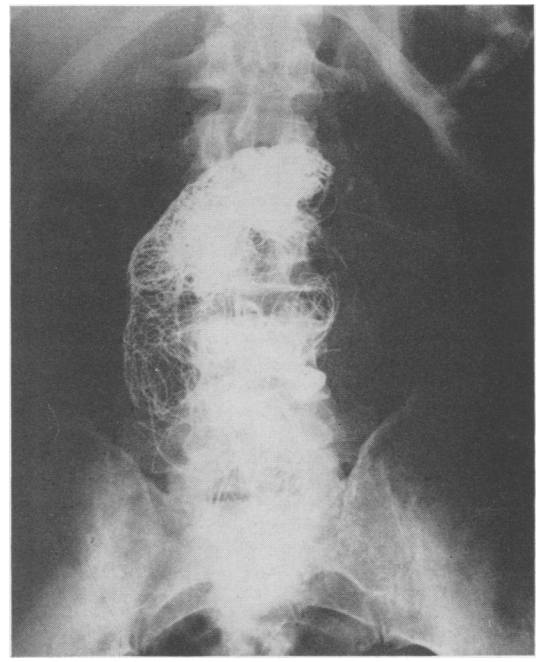


FIG. 4.—A roentgen ray of the abdomen taken after wiring and electrothermic coagulation of a very large arteriosclerotic aneurysm. The lesion has been stabilized now in excess of eight years since operation. Note concentration of wire at the upper aortic—aneurysm junction for its impedance effect.

Though the arteriosclerotic aneurysm of the abdominal aorta does not cause bone eroision and the victims are spared the boring, radicular pain characteristic of the syphilitic aneurysm, nevertheless they do frequently have pain, the implications of which may be ominous. For example, the aneurysm illustrated in Figure 3 ruptured a few hours after the roentgenogram was made and the patient was dead 45 minutes

later. This man, in his mid-fifties, was known to have an expanding arteriosclerotic aneurysm of the abdominal aorta. Seven days before the roentgen ray film was taken he had complained of "vague fleeting pains in the aneurysm." A recent analysis of 26 cases of arteriosclerotic aneurysm of the abdominal aorta[4] affords convincing evidence that the sudden appearance of deep seated abdominal pain, no matter how fleeting or vague, the development of low back pain radiating to the loin, inguinal region, hips or legs is usually a warning of impending disaster.

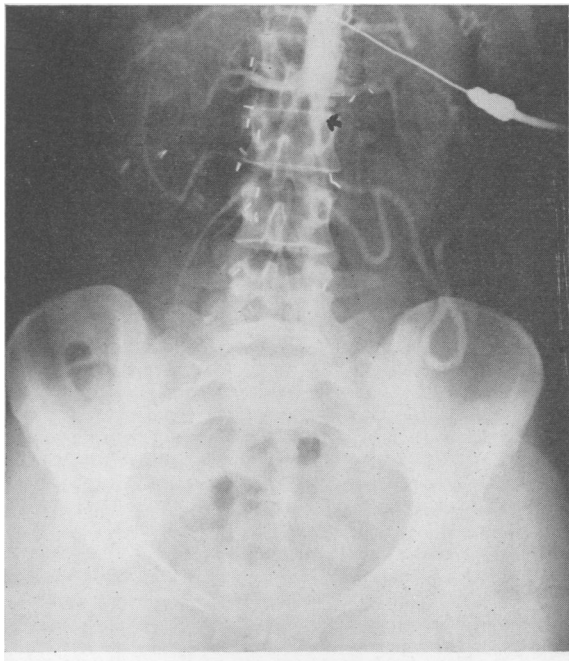


FIG. 5

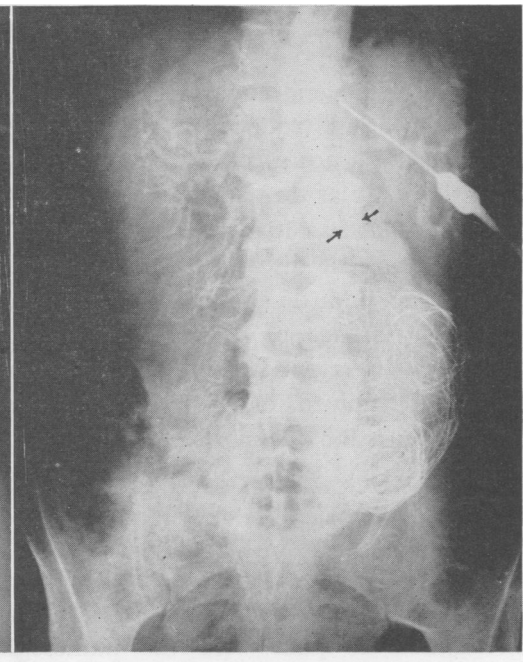


FIG. 6

FIG. 5.—Abdominal aortogram of Case 1 showing complete occlusion of the aorta at the site of banding immediately below the origin of the inferior mesenteric artery (see arrow).

FIG. 6.—Aortogram of Case 2 two weeks after operation. Compare the degree of constriction at the band site (see arrows) with Figure 8, which shows the ideal amount of aortic constriction.

Again and again we have been able to correlate pain with pathologic findings. In another case a man known to have a symptom free arteriosclerotic aneurysm of the abdominal aorta suddenly developed pain in the abdomen over the lower portion of the aneurysm. The pain disappeared after medication in the hospital two hours later, but tenderness over the lower pole of the aneurysm persisted. At operation four days later a secondary sacculation of recent origin was noted protruding anteriorly from the lower half of a large fusiform aneurysm. The secondary sacculation was the shape and size of an egg. It was capped by an area of anemic necrosis, to which the peritoneum was densely adherent. Needling the aneurysm revealed the secondary sac to be clotted "brim full" and its consistency to be firm. The mechanism in this case was quite obvious: the man, who previously had been symptom free, rather suddenly developed a rapidly expanding, secondary sacculation in an area of the anterior sac wall, weakened by cholesterol deposits and poor blood supply. The above coincided with the onset of pain and finally, as the result of prompt and adequate clotting, the process was stabilized and imminent rupture prevented for the time being.

It has been our observation that the above described mechanism is a frequent occurrence in arteriosclerotic aneurysms of the abdominal aorta. We have repeatedly seen at operation one or more secondary sacculations up to two or three centimeters in diameter, areas which may or may not have warned the patient of near disaster by a twinge of pain. A study of the pathology of the arteriosclerotic aneurysm with particular reference to weakness of the sac wall due to degenerative changes and lack of blood supply makes it a far more dangerous lesion than the syphilitic aneurysm, and such has been our experience with its clinical behavior.

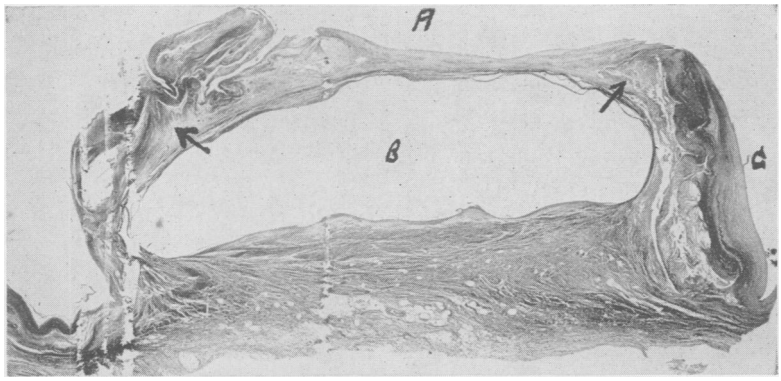


FIG. 7.—A photomicrograph of a longitudinal section of the aorta at the band site seven months after operation in Case 2 (trichrome stain). Note the usual atrophy of the aorta wall between A and B (A marks the lumen side of the aorta, B marks the site of the rubber band). Observe that fibrous tissue (dark-stained areas) has grown down into the adventitia at the upper (right) and lower (left) edge (see arrows). This excess fibrous tissue has invaded the aorta wall and reinforced it at the danger site; namely, the upper and lower edges of the band. Note further the extensive invasion of the full thickness of the aorta at C on the cardiac (high pressure) side of the rubber band.

We now wish to call attention to a feature which in our opinion has not been adequately emphasized; namely, the fact that the arteriosclerotic aneurysm sac is subjected to the "seesaw" strain of a greatly exaggerated pulse pressure. To visualize the magnitude of this added strain one only has to realize that the oscillometric readings over an unobstructed leg artery in a patient having severe arteriosclerotic involvement of the aorta will be exaggerated four or more times normal values. The mechanism of this exaggerated hemodynamic strain upon the arteriosclerotic aneurysm is now well understood; namely, the arteriosclerotic aorta has lost its elastic recoil and the entire energy of ventricular systole is converted to energy of flow-result, the propagation of a greatly exaggerated pulse wave with each heart beat.

TREATMENT OF THE ARTERIOSCLEROTIC ANEURYSM OF THE ABDOMINAL AORTA

There is one fortunate feature of the arteriosclerotic aneurysm of the abdominal aorta; namely, it regularly arises three or more centimeters distal to the renal arteries. This important feature permits the prospect of carrying out gradual occlusion of the aorta with the aneurysm *pari passu* with the development of collateral circulation. This accomplished, all the requirements for absolute cure would be fulfilled.

In the early forties, having a backlog of five years experience with the electrothermic method of wiring with progressive

FIG. 8

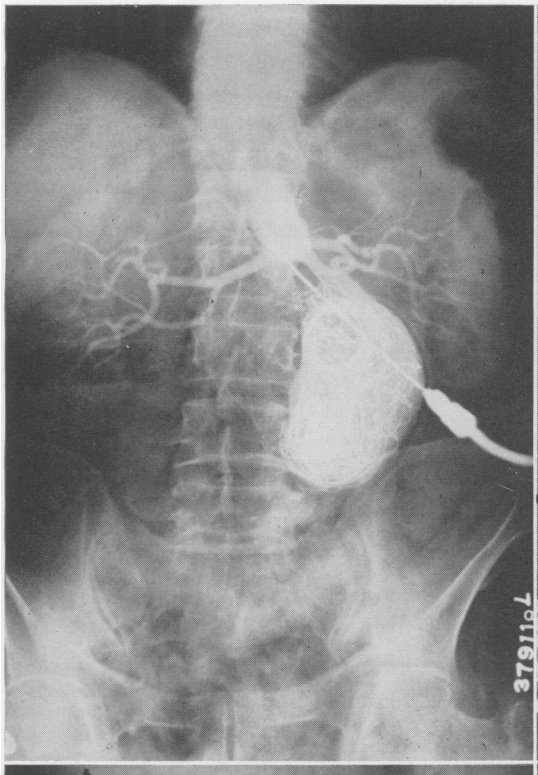
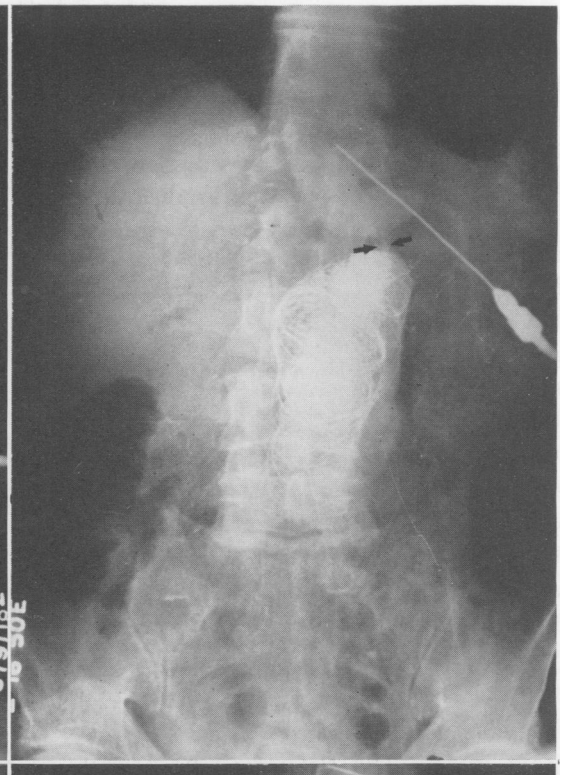
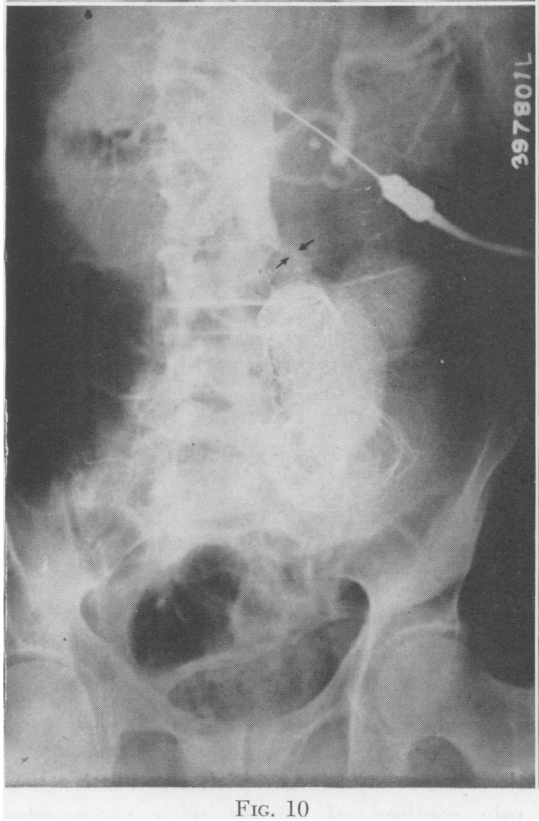


FIG. 9





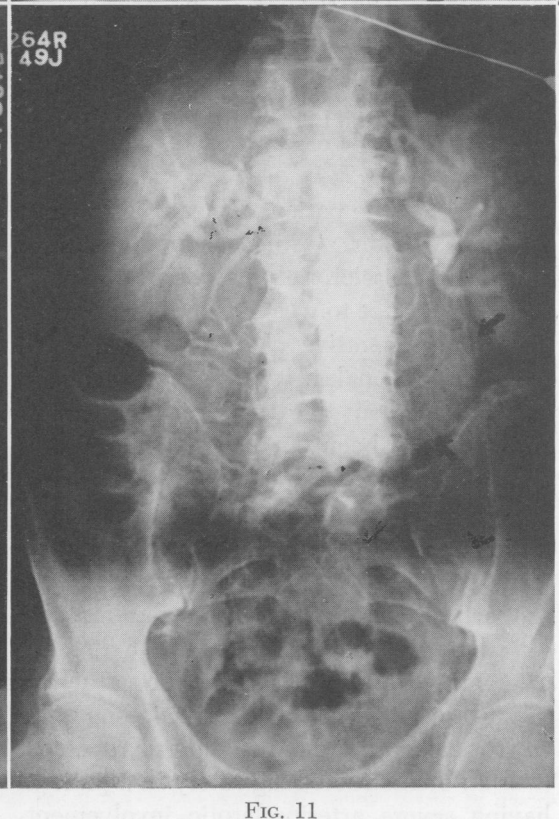


FIG. 10

FIG. 11

(See legends on opposite page.)

endoarterial occlusion in the treatment of syphilitic aneurysms, we undertook the treatment of aneurysms of the arteriosclerotic variety. We have made preliminary reports,[3-5] and now have follow-up observations up to as long as eight years (Fig. 6) upon cases of arteriosclerotic aneurysms of the abdominal aorta treated in this manner. The electrothermic method having previously demonstrated its worth as a safe method of selective clotting based upon differential rate of blood flow, it was but a natural procedure to concentrate wire in the aorta immediately proximal to the arteriosclerotic aneurysm for its impedance effect upon blood flow (Fig. 4). In this way the physical state of turbulence could be attained in the blood stream which effectively reduces the abnormally high pulse wave, as recorded by oscillometric readings distally and, therefore, greatly reduces strain upon the aneurysm itself.

We have employed the above method of concentrating wire in a ball in the aorta to promote endo-arterial occlusion with wiring and electrothermic coagulation of the aneurysm immediately below on many cases *with success*. The main objections to the above technic are that it is tedious in operation and not infrequently must be carried out in two operative stages.

In an effort to overcome the above objections and thereby achieve a one-stage operative procedure, we once more directed our attention to the heretofore unsolved problem of progressive constrictive occlusion of the human aorta. Many of us are all too familiar with the disastrous results that have followed such attempts in the past. The facts are that all constrictive devices heretofore employed in a manner to really substantially reduce the lumen of the human aorta have resulted in such a high incidence of death from hemorrhage due to pressure necrosis as to make their use prohibitive. If, on the other hand, a method were devised in which the arteriosclerotic aorta could in one operative stage be safely constricted to the size of a cigarette immediately proximal to an aneurysm, the strain of a greatly exaggerated pulse pressure would be removed. Attention has previously been called to the fact that arteriosclerotic aneurysms of the abdominal aorta regularly arise well distal to the renal arteries, and, in this respect, they are ideally located for constrictive banding of the aorta immediately proximal to the aneurysm.

Having observed the fibroplastic reaction to Polythene with dicetyl phosphate (DuPont) when imbedded in tissues, it seemed likely to us that this substance if placed beneath a band upon the human aorta may prevent the occurrence of hemorrhage. We reasoned that fibroplasia, due to the irritant action of the plastic film, would proceed rapidly along the borders of the constricting band, and this critical area would be reinforced well ahead of the occurrence of anemic necrosis beneath the band.

FIG. 8.—An aortogram made ten months after operation in Case 4. The constriction of the aorta at the band site is actually to the size of a cigarette, which we consider is ideal.

FIG. 9.—An aortogram of Case 7, made four months after the first and two weeks after the second operation. Note the concentration of a ball of wire immediately distal to the site of the band. This was introduced at the second operative stage for its impedance effect. A close study of this final aortogram makes us doubt if any blood is passing beyond the band. Note the extreme angulation of the aorta at the level of the left renal artery; the right kidney has been removed.

FIG. 10.—Aortogram of Case 8. Note lower level of band site at arrows. The rubber band is placed well below the renal arteries in this case. The degree of occlusion of the aorta is correct in this case. The shadow observed to the right of the upper pole of the aneurysm originates from some sodium iodide spilled on the skin.

FIG. 11.—An aortogram of a 79-year-old man taken December 8, 1949. The patient remained symptom free of his aneurysm until a few hours before death from rupture May 24, 1950. This case is shown to demonstrate the dangers of natural eccentric clotting. Note that the opacified column of blood hugs the sac wall along the right border but there is a great deal of clot between the blood stream and sac wall (see arrows) along the left border of the large arteriosclerotic aneurysm.

Employing a slingshot rubber band encased in three layers of Polythene-dicetyl phosphate film, the abdominal aorta was constricted above an aneurysm in a 31-year-old woman. This woman, our first case, was operated upon June 19, 1948 (Fig. 5).

Case 1.—This patient, 914070, was admitted to Presbyterian Hospital June 17, 1948, and discharged June 29, 1948.

C. C.: There was pain in the lumbar region radiating to the loins of three months duration, and more recently pain in the left lower quadrant of the abdomen. The patient gave a negative history of lues or other infections. Her health prior to the present illness had been excellent.

Pex: T. 98.6 F.; P. 100; R. 20; and B. P. 120/80. She was a healthy appearing woman who on complete examination presented one positive finding; namely, a pulsating mass in the lower abdomen. There was a palpable thrill over the mass and a systolic bruit was heard. Femoral pulsations were normal.

Laboratory: Klein test was negative; W.B.C. 10,900; R.B.C. 4,000,000; Hgb. 13.3 Gm. Urine examination normal. Roentgen rays of heart and spine reveal no pathology.

At operation the abdominal aorta appeared small but a short distance above the bifurcation it expanded into a fusiform aneurysm which measured 3 cm. in diameter. The sac wall appeared inflamed, was firm, and apparently contained considerable clot. For the reason that the aneurysm may be of a mycotic variety and the fact that it contained a great deal of clot, wiring and electrothermic coagulation was not carried out. A slingshot rubber band wrapped in three layers of polythene-dicetyl phosphate film was passed about the aorta 2 cm. proximal to the aneurysm. The band was tightened to occlude the aorta and then gradually released to the point of appearance of a palpable thrill at the site of the band. At this point the rubber band was transfixed with two mattress sutures of 00 braided silk. Pulsation in the aneurysm and iliac arteries became very faint. The oscillometric readings fell in the legs to a maximum of one division from the upper one-third. The patient was mobilized early postoperatively and showed no evidence of circulatory insufficiency beyond some tiredness in the legs upon walking. A bilateral lumbar sympathectomy was performed before discharge from the hospital.

On January 22, 1949 (6 months postoperative), the patient was admitted for aortogram. She had remained entirely free of her preoperative pain, was working hard, and had no claudication pains. On examination no definite mass could be made out, and there was no pulsation palpable at the site of the aneurysm. A loud systolic murmur was heard just above the level of the umbilicus. The oscillometric readings from the upper one-third of the legs were a maximum of a half a division compared to one division soon after operation. The added fall of the oscillometric readings and the absence of palpable femoral pulsations suggested complete closure of the aorta. The persistence of a systolic bruit, on the other hand, suggested that a very tiny stream of blood might be passing through the aorta at the band site. Aortogram (Fig. 5) shows the aorta to be completely occluded at the band site distal to the renal arteries.

It seems reasonable to conclude from all evidence at hand that the aorta in this young woman went on to complete occlusion at the site of the band. This progressive closure took place gradually following operation, and it is but reasonable to ascribe it to additive constrictive fibrosis due to the irritant dicetyl phosphate in the Polythene film.

Cooper and his co-workers have recently published a splendid paper[6] on the experimental production of gradual occlusion of the dog's aorta using Polythene containing dicetyl phosphate beneath tantalum bands. In their series of 19 dogs so banded, the aorta became completely occluded in ten to 12 weeks after operation in four dogs; an additional aorta became completely occluded after 18 weeks; there was partial increase in occlusion of the aorta in eight additional dogs; and, finally, in only three dogs out of 19 was there no change in the degree of occlusion of the aorta. One wonders if perhaps the latter three were not old arteriosclerotic dogs. Certainly the possible influence of severe arteriosclerosis upon the degree of fibroplasia was a burning question with us in January, 1949, when we decided to place a slingshot rubber band wrapped with Polythene around an arteriosclerotic aorta. Reasoning that it takes blood supply to build fibroblasts, though there be an adequate irritant pres-

ent, we considered it would be fortunate if sufficient fibrous tissue reinforcement took place along the edges of the rubber band to prevent hemorrhage.

We are now happy to report seven additional cases operated upon as in Case 1, all of which had arteriosclerotic aneurysm of the abdominal aorta. Furthermore, all the cases have been followed well beyond the expectancy period of hemorrhage from anemic necrosis at the band site.

Case 2.—This patient, 937619, a 76-year-old man, was admitted January 6, 1949, complaining of discomfort in the region of a pulsating mass and a weight loss of 17 pounds. A diagnosis of arteriosclerotic aneurysm of the abdominal aorta was made. At operation January 8, 1949, the aneurysm was found to arise from the aorta 3 cm. distal to the renal arteries and extend to the bifurcation. It was fusiform in shape and measured 12 cm. in diameter. A single thickness of synthetic, slingshot rubber, wrapped in three layers of Polythene-dicetyl phosphate film was passed around the aorta just proximal to the aneurysm. A ten-meter segment of insulated coin silver wire was distributed within the aneurysm, and the ends of the wire were connected for heating. Before tightening the band a rate of blood flow measurement was taken by applying enough current (4.2 amperes) to raise the temperature of the wire 15°C. above body temperature. Then the band was tightened to the point of occlusion of the aorta, at which point the amperage fell to 3. Finally the band was released gradually to a point at which the rate of blood flow rose to 80 per cent of normal; namely, 3.4 amperes, and here the band was fixed, employing two mattress sutures of 00 silk. This point of adjustment of the band corresponded to the appearance of a palpable thrill at the band site and gave an oscillometric reading of one-third of a division from the upper one-third of the leg. Fifty milligrams of heparin were then injected into the aneurysm. The ten-meter segment of wire was heated to 80°C. for a ten-second period, and the ends of the wire were pushed through the needle into the aneurysm. A second ten-meter (33 ft.) segment of wire was introduced and heated.

The patient did exceedingly well following operation except that a rise of the oscillometric readings in the legs to their preoperative level indicated that a mattress suture had cut through the synthetic rubber. This was confirmed by an aortogram made on the fourteenth postoperative day (Fig. 6). The roentgenogram reveals the aorta to be constricted to approximately 60 per cent at the site of the band—just the amount we now know to produce the maximum degree of the dreaded nozzle effect of increased strain upon the aneurysm below. In retrospect, what we should have done would have been to re-operate on the patient and insert a ball of wire into the aorta at the band site for its impedance effect upon blood flow.

Though there was evidence of considerable clotting in the aneurysm by aortogram, nevertheless, after six months the patient began to develop pain. Attacks of severe lumbar pain radiated into the left loin and groin, down the left leg to the heel. Some three weeks after onset the patient was re-admitted to the hospital, where he promptly died of shock due to a ruptured retroperitoneal hematoma. The necropsy was exceedingly informative. There was a rupture of the sac on the posterior wall of the aneurysm 1 cm. long. This opening was adequately sealed by old retroperitoneal hemorrhage and undoubtedly accounted for his first attacks of pain. On the anterior sac wall was a recent rupture 1 cm. in length which rapidly caused a hematoma that suddenly burst through the peritoneum.

Most important of all in this case was the aorta at the site of the synthetic rubber band. The entire band, including the underlying polythene, was encased in firm and abundant scar tissue. The ends of the rubber band were dissected, and it was noted that the proximal silk mattress suture had cut through the synthetic rubber as predicted. The size of the constricted aorta beneath the band was that of a fountain pen, when it should have been ideally the size of a pencil or slightly less. We have repeatedly done rate of flow measurements constricting the aorta varying degrees and have found the greatest exaggeration of rate of blood flow (nozzle effect) when the aorta is closed down approximately 60 to 70 per cent. It is reasonably certain that the cutting through of the silk ligature in this case contributed to an increased strain upon the aneurysm and was responsible for its rupture. In all subsequent cases double thickness of natural rubber bands have been employed. Furthermore, appreciating the narrow limits of adjustment in applying the bands between the nozzle effect of greatly increased strain upon the aneurysm on the one side and acute circulatory insufficiency of the extremities on the other indicates to us the necessity for great caution.

Figure 7 is a microphotograph of a trichrome stained longitudinal section of the aorta at the band site. Note the great ac-

cumulation of fibrous tissue (dark stained areas) along the border of the band site. This evidence of tissue reaction to the dicetyl phosphate in the polythene film which lay in contact with the aorta accounted for the absence of hemorrhage at the band site in this case.

Case 3.—This patient, 917904, a 54-year-old male furrier, was admitted to the Presbyterian Hospital, July 30, 1948, for operation upon an arteriosclerotic aneurysm of the abdominal aorta. The patient gave a past history of hypertension and anginal syndrome. There was no history of lues. There had been a rapid weight loss of 15 pounds.

For six and a half years the patient had complained of a dull pain in the midabdominal region. There was a filling defect of the stomach by roentgen ray, and in 1942 the patient was explored when the diagnosis of aneurysm of the abdominal aorta was established. For a period three weeks prior to admission the patient complained of diffuse abdominal pain and pain in the back of such severity as to require large doses of Demerol for relief.

An aortogram made August 3, 1948, confirmed the diagnosis of aneurysm of the abdominal aorta. The aneurysm was fusiform in type and measured 12 by 6 cm. Unfortunately, operation upon this aneurysm was postponed during this admission because the patient suffered an anterior myocardial infarction.

The patient was re-admitted and brought to operation January 22, 1949, some 5 months following the coronary occlusion. Under cyclopropane anesthesia he went through the operation of wiring and electrothermic coagulation of the aneurysm with application of a constrictive sclerosing band upon the aorta without event. The pulsations in the arteriosclerotic aneurysm were greatly reduced following operation. The oscillometric readings were reduced in the legs to one-sixth of their preoperative value. The patient was discharged on the twelfth postoperative day, ambulatory and free of his preoperative pain.

Over the months following operation, the patient has gained weight and strength, continued to work and is free of claudication symptoms. A recent aortogram (April 5, 1950) reveals no change in the size of the aneurysm.

Case 4.—This patient, 957724, a 65-year-old Jewish merchant, was admitted to Presbyterian Hospital June 8, 1949. For 4 months he had suffered from recurring attacks of severe upper abdominal pain. On examination a pulsating mass was noted in the abdomen to the left of the umbilicus.

A diagnosis of arteriosclerotic aneurysm of the abdominal aorta was made. On June 11, 1949, the patient was operated upon, the aneurysm wired, and a slingshot rubber band encased in polythene was placed upon the aorta proximal to the aneurysm but distal to the renal arteries.

The patient convalesced nicely from the operation. An aortogram was made before discharge from the hospital and this roentgenogram compared with a recent aortogram (ten months after operation) reveals no change in the size of the aneurysm. Furthermore there appears to be no change in the degree of constriction of the aorta. The aorta appears to be constricted at the band site approximately 85 per cent the ideal amount. see Figure 8. Following operation the patient has been free of his preoperative pain. He is active and has no claudication pain in the legs.

Case 5.—This patient, 957405, was a 55-year-old white male carpenter admitted to the Presbyterian Hospital, June 13, 1949, with the chief complaint of fatigue. The present illness began a year ago with easy fatigue after slight exertion, paraesthesias of the hands and feet. Two months previous to admission an aneurysm of the abdominal aorta was noted by the L. M. D. There is no history of lues and the serology is negative. There had been a loss of 16 pounds in weight during the 6 weeks previous to admission.

At operation June 18, 1949, an arteriosclerotic fusiform aneurysm of the abdominal aorta was noted. The aneurysm arose some 6 cm. distal to the renal arteries and extended to a point 3 cm. proximal to the bifurcation. Wiring and electrothermic coagulation of the aneurysm was carried out. Finally a slingshot rubber band wrapped in 16 thicknesses of polythene film containing the irritant dicetyl phosphate was applied about the aorta just proximal to the aneurysm.

The patient convalesced from the operation uneventfully. A letter from the patient's physician in Utah 9 months after operation stated that the patient had been working symptom free when suddenly he contracted virus pneumonia and died.

Case 6.—This patient, 960958, was admitted to the Presbyterian Hospital July 26, 1949. He was a 62-year-old Polish man who for 6 months complained of lumbar and lower abdominal pains. On examination a pulsating tumor was felt in the upper abdomen and to the left of the umbilicus. A bruit could be heard over the mass.

A diagnosis of arteriosclerotic aneurysm of the abdominal aorta was made. Dr. Ralph Deterling operated upon this patient July 29, 1949. At oper-

ation a fusiform aneurysm was noted arising from the aorta 3 cm. below the origin of the renal arteries. A slingshot rubber band encased in 8 layers of polythene film was placed upon the aorta. The patient did well postoperatively. The oscillometric readings in the leg were reduced to one-half of a division. Recent letters from the patient and his doctor report him to be symptom free. The patient has failed to return for check-up studies and possible wiring of his aneurysm.

Case 7.—This patient, 970010, a 74-year-old man, a retired mechanic, was admitted to the Presbyterian Hospital, September 23, 1949, complaining of abdominal pain and backache. He gave a past history of syphilis with a penile sore at age 39. He had received extensive antiluetic therapy since 1932. A spinal fluid was negative in 1935, but the blood showed an occasional positive Kline. In 1939 a prostatectomy was performed for carcinoma. Although there was no palpable evidence of recurrence, an orchectomy was done in 1943. A right nephrectomy was done in 1944 for pyelonephritis.

Suddenly on September 13, 1949, the patient suffered severe pain in midabdomen radiating to the groin and left back. The patient was admitted to the Roosevelt Hospital where a large aneurysm of the abdominal aorta was noted, and a tentative diagnosis of beginning rupture was made. His condition became somewhat stabilized and he was transferred for wiring and electrothermic coagulation ten days later.

Examination on admission revealed a well-developed man appearing younger than his stated age except for evidence of marked arteriosclerosis and moderate weight loss (15 pounds). The heart was not enlarged to percussion (blood pressure 160/108). Heart rhythm normal. A blowing systolic murmur was heard over the precordium, maximum over the mitral and aortic areas. A large pulsating mass was present over the site of the abdominal aorta. A loud bruit could be heard over the mass.

At operation October 8, 1949, a very large fusiform aneurysm extended from just below the origin of the renal arteries down the aorta to the bifurcation. The fusiform sac spotted with areas of cholesterol degeneration was typical of arteriosclerotic aneurysm. As a most probable cause of his recent severe pain (no old or freshly extravasated blood was noted about the aneurysm) was the presence of what appeared to be recent secondary sacculations from the thin fusiform sac wall. These areas measured several centimeters in diameter and obviously were the site of anemic necrosis.

At operation a slingshot rubber band wrapped with 18 layers of polythene film containing an irritant, dicetyl phosphate, was applied around the aorta just distal to the left renal artery. Insulated wire was introduced into the aneurysm and heated to the total of three 10-meter segments. Due to the high rate of blood flow, however, it was only possible to heat one of the 10-meter segments to the desired temperature of 80°C. And it was realized that possibly a second stage operation would be required.

Following this operation the patient's pain was almost, but not entirely, relieved, although there was marked reduction of the pulsation in the aneurysm. Accordingly, on February 2, 1950, 4 months following the first operation, a second stage wiring of the aneurysm was done. Inspection of the aorta at the site of constriction revealed the band firmly encased in scar tissue. Just distal to the site of constriction, in the upper pole of the aneurysm, 150 ft. of wire was concentrated for its impedance effect upon blood flow (see Fig. 9). Finally, a 10-meter segment of insulated wire was distributed in the aneurysm and heated to 80°C. for a 10-second period. Following the above procedure, the oscillometric readings from the legs had fallen from 9 to 3 divisions, and the aneurysm had become quite firm and pulsated very little. The patient's convalescence was tedious but, on the whole, satisfactory. The last remnants of abdominal pain are now gone. Follow-up May 15, 1950: his strength and appetite have improved markedly. He has gained 16 pounds in weight, is active, and suffers from no claudication pains in the legs.

Case 8.—This patient, 987512, a 65-year-old railroad conductor, was referred for admission to the Presbyterian Hospital, February 22, 1950. For two years prior to admission the patient had dyspnea on stair climbing. He had suffered five attacks of angina and suffered from intermittent claudication in the legs.

The present illness dated back two weeks with the onset of "heavy pressure" in the lower abdomen. On examination the blood pressure was 160/100. The heart percussed somewhat enlarged. The abdomen was abnormal in that a pulsating mass was present to the left of the umbilicus. The oscillometric readings varied from 10 to 7 divisions in the two legs.

At operation February 25, 1950, a fusiform aneurysm of the arteriosclerotic variety was noted to arise in the abdominal aorta some 6 cm. distal to the renal arteries. The aneurysm measured 8 cm. in diameter at its widest portion. Through a special needle a 10-meter segment of insulated

wire was distributed throughout the aneurysm. Previous to this the aorta immediately above the aneurysm had been encircled by a rubber band encased with polythene plastic film containing an irritant, dicetyl phosphate. A rate of blood flow measurement was made; raising the temperature of the wire to 53°C., *i.e.* 15°C. above blood temperature, required 4.2 amperes. Then, upon tightening the band upon the aorta to just beyond the point of disappearance of the thrill it required only 3 amperes to raise the temperature of the wire 15°C. Finally, releasing the band to just the point of re-appearance of a thrill at the site of the band resulted in an increase in the rate of blood flow through the aneurysm to the point that 3.4 amperes were required to raise the temperature of the wire 15°C. This was the site at which the band was fixed. The patient was heparinized at this point and the wire heated to 80°C. to deposit a clot stimulating protein coagulum upon its surface. Subsequently a second 10-meter segment of wire was distributed within the aneurysm and heated. The above procedures caused an increased firmness in the aneurysm with diminution in pulsation to the barely perceptible point; the oscillometric readings in the legs were reduced from a pre-operative value of 9 divisions to three-quarters of a division.

The patient convalesced uneventfully. He was mobilized early and walked about considerably without symptoms of claudication in the legs. An aortogram made on the eighth postoperative day reveals the aorta constricted to the diameter of a cigarette at the band site (see Fig. 10).*

DISCUSSION

Some idea of the problem of gradual occlusion of the human aorta may best be attained by citing previous experience. Since Sir Astley Cooper[7] reported the first case of ligation of the abdominal aorta in 1817 there have been reported 36 additional cases. In view of the fact that only eight of these cases survived one year or more following operation, it seems likely that many operative attempts have gone unreported.

Halsted,[8] early realizing the dangers of complete (one stage) ligation of certain large arteries, including the aorta, conducted exhaustive experiments with the use of silver and aluminum bands introduced by a special instrument. Matas[9] also suggested the use of malleable aluminum bands as a means of partial occlusion preliminary to ligation of large arteries. Reid[10] demonstrated, however, that atrophy of the vessel walls takes place beneath constrictive bands placed upon large arteries. He concludes that this so weakens the vessel wall as to cause a high incidence of late hemorrhage at the band site. Owens,[11] on the other hand, noted in 1942 a higher incidence of success when employing slingshot rubber bands upon the thoracic aortas of dogs, A likely explanation is that rubber, an extremely resilient substance in comparison with metal bands, would stretch somewhat with the passage of each pulse wave down the aorta. This served perhaps to delay the rate of atrophy taking place in the vessel wall beneath and at the edges of the band. And, important too, the softer rubbed edges are everted, the rubber band assuming a slightly hourglass configuration when secured with two mattress-silk sutures. It is these features of the slingshot rubber band which make it, in our opinion, the ideal constricting material to be employed in conjunction with an underlying irritant plastic film for purposes of partial occlusion of large arteries, especially, the aorta.

The observations of Pearse[12] in 1940, noting a profound fibrous tissue response to cellophane (DuPont) placed about the aorta of dogs, pointed the way to safe and successful closure of the human abdominal aorta. Whereas Pearse could not always demonstrate complete closure of the aorta of the dog following wrapping with an irritant plastic film, this is but to be expected. In the first place, cellophane and other irritant plastic films do not possess the sturdy physical characteristics that would make them suitable for sustained constriction of the aorta against the incessant pounding of

* Acknowledgment is made to Drs. Robert Deterling and Robert Ball for the aortograms on these patients.

the pulse wave. In the second place, assuming that one could, with a great deal of difficulty, wrap, turn after turn, many layers of plastic film about a human aorta, there is that fine and difficult part of adjustment to just the right degree of occlusion of the aorta. Experience has taught us that in cases of aneurysm of the abdominal aorta too much occlusion runs the risk of acute circulatory insufficiency in the extremities and too little occlusion (under 75 per cent) leads to a greatly increased strain upon the aneurysm below (nozzle effect—see Case 2). Finally, assuming that one could adjust the encircling plastic film to just the right degree of constriction of the aorta so as to safely remove the exaggerated pulse strain upon the aneurysm below, then comes the problem of fixation—silk sutures in plastic film just do not hold well against tension.

The important fact we have demonstrated in eight cases is that the irritant action of polythene film containing dicetyl phosphate, when placed around the abdominal aorta beneath a constricting slingshot rubber band, is adequate to protect against hemorrhage at the band site. This is so in spite of the fact that in seven of the eight cases the aorta was the site of severe arteriosclerotic degeneration. Further proof of the development of abundant fibrous tissue as the result of the irritant action of the plastic film at the band site is (1) progression to complete occlusion of the aorta in Case 1, (2) the demonstration of excessive fibrous tissue at the site of the band in Case 2 (see Fig. 7).

We have follow-up evidence that the clinical course of aneurysms of the abdominal aorta can be favorably influenced by employing endo-arterial wiring for its impedance effect and the electrothermic method for controlled, concentric clotting (see Figs. 2 and 4). The addition of a safe method of constrictive, partial occlusion of the aorta immediately proximal to the aneurysm now enables us to achieve for the first time a definitive, curative procedure in one operative stage (see Fig. 8).

In modern days of good anesthesia, electrolyte balance and control of blood volume, it is a source of delight how well these people with advanced arteriosclerosis get along with this combined operation. In retrospect, by far our greatest sorrow, numerically speaking, have been those patients who, for one reason or another, failed to reach the operating table. There is certainly one thing we doctors can do today, and that is to recognize the arteriosclerotic aneurysm of the abdominal aorta for what it most certainly is; namely, a treacherous disease. Yet every now and then we catch ourselves trusting one a little too long (see Fig. 11).

SUMMARY

The electrothermic method of coagulating aneurysms employing insulated coin silver wire is discussed with special reference to its special features, efficiency, and safety. The special features that insure controlled clotting make it safe to employ the electrothermic method in the treatment of arteriosclerotic aneurysms of the abdominal aorta. The incidence, clinical behavior, and pathology of the arteriosclerotic aneurysm of the abdominal aorta are discussed.

A method of constrictive partial occlusion of the abdominal aorta is presented with a report of eight cases. The method has proved safe from hemorrhage at the site of constriction consistently even though seven of the eight cases had marked arteriosclerotic degeneration of the aorta. The operation may be performed in conjunction with wiring and electrothermic coagulation in one stage for the definitive cure of arteriosclerotic aneurysms of the abdominal aorta.

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