A Method of Treatment for Complicated Aneurysms of the Abdominal Aorta

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WHILE tremendous strides have been made during the past 15 years in vascular surgery, occasionally aortic lesions are not amenable to replacement or bypass methods. Such instances in the treatment of abdominal aortic aneurysms in 40 patients between 1957 and 1967 constitute the basis for this report.

Prior to the first successful resection of an abdominal aortic aneurysm by Dubost[4] in 1952, several methods of treatment were advocated. Proximal ligation usually resulted in clot formation within the aneurysm. This prevented rupture but distal parts were subject to ischemic effects. Intraluminal wiring,[1] at times, created sufficient clot to withstand pressure on the thinned-out aortic walls. External wrapping with cellophane[9] and fascia[11] produced abundant scar, but this was insufficient to prevent eventual rupture.

Following the initial success by Dubost in replacing an abdominal aortic aneurysm, improvements in technic and graft materials were developed to provide relatively safe methods. Individual preferences as to types of plastic grafts used, rather than controlled studies regarding advantages of each, seem to influence the selection of materials and textile properties. Dacron and teflon grafts, knitted or woven, can be inserted successfully with about the same efficacy. The surgical treatment of abdominal aortic aneurysms is commonplace and low morbidity and mortality are generally accepted. Despite these advances, occasional patients whose cardiovascular, renal, or respiratory systems are diseased, cannot withstand aortic resections. Such patients will be discussed.

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Materials

During the past 10 years, 40 patients had conditions contraindicating resection of abdominal aortic aneurysms. All of the patients had symptomatic aneurysms and generalized cardiovascular disease, most had advanced emphysema. At the same time, all were considered to have a more favorable outlook through attempted mechanical repair than would be expected with nonoperative treatments suggested by Estes, Kampmeier, Blakemore, Gliedman and others.[6]

All of the patients (Table 1) were poor operative risks, and there were such complicating factors as (1) poor runoff vessels, (2) extensive or multiple aneurysms, (3) aneurysms capable of changing diameter according to pressure alterations, and (4) combinations of the above factors.

After observation of several patients with nonresectable aortic aneurysms, teflon cloth was proposed as an external support to prevent expansion of the aneurysm if and when the cloth became a fixed part of the aortic wall. To determine whether the graft would fuse, teflon cloth was applied externally to aortas of 25 dogs. The grafts became densely incorporated in the adventitia of the encased aorta in about 3 weeks and became an integral part of the aortic wall. This external graft was tolerated well in

the dogs for 6 months and was deemed feasible for trial in selected human patients (Fig. 1).

Since abdominal aortic aneurysms appear to expand anteriorly and laterally, it was considered that a covering incorporating all the aortic circumference except the vertebral attachments, would prevent further expansion. The dangers of dissecting the aortic aneurysm from the vertebral attachments were recognized. This theory was advanced to Dr. Edward W. Merrill, Professor of Chemical Engineering [8] at the Massachusetts Institute of Technology, who has great interest in rheology. He answered as follows, "I am quite sure that there is a very good rationale for the results that you observe, namely protection against expansion by partially enclosing the aneurysm with a teflon cloth. There seems to me to be two principles involved. One is the hoop principle (Fig. 2) that I mentioned at Brooklyn. In effect, this prinicple states that with a given pressure inside of a tube and a given pressure outside of the tube, the tension in the tube wall will be directly proportional to its diameter. In the case of aneurysm, therefore, if we consider the intra-arterial pressure and the ambient tissue pressure fixed, a doubling in diameter of the aorta by expansion would produce twice as much tension per inch of running length as existed before. Thus the situation rapidly goes from bad to worse. The second principle may or may not be relevant to aortic wall material but it is a well known fact that tubes made from crystalline polymers, such as polyethylene, will blister, that is, expand over *only a part of their surface,* under the action of internal pressure. This comes about because when the tension in the tube wall exceeds a certain critical value, the polymer suddenly starts to "draw" ("neckdown") locally rather than uniformly, and the molecules radically reorient themselves forming a kind of blister. It is conceivable that collagen and other biological polymer substances in the aortic wall might behave analogously once they have been stretched beyond a certain tension.

TABLE 1. *The Number of Patients in the Various Categories of Complicating Factors Necessitating External Aortic Graft*

	No. Pts.
Poor runoff (calcified vessels, etc.)	13
Extensive (or multiple) aneurysms	7
Varying-sized aneurysms (expanding)	4
Combination (2 or more of above)	16*
Total operations	40

* Of this number, 9 were intolerant to anesthesia or operative procedure.

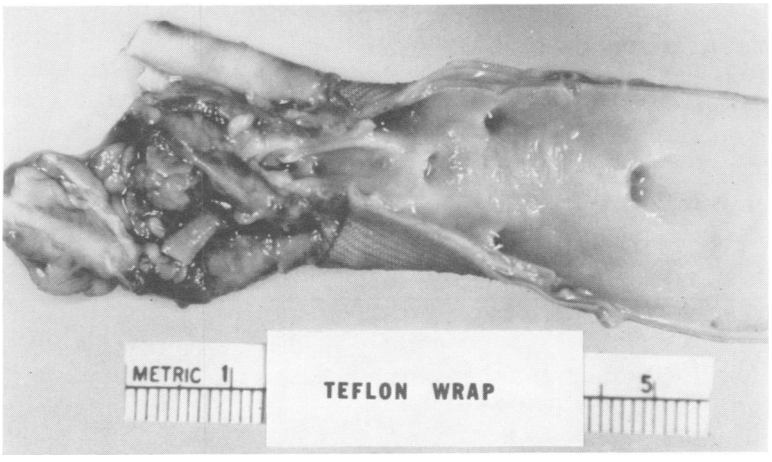

FIG. 1. A canine terminal aorta specimen is shown covered with knitted teflon 3 months previously. The adventitia is firmly fixed to the cloth by fibrous tissue which has grown through and around the interstices of the material.

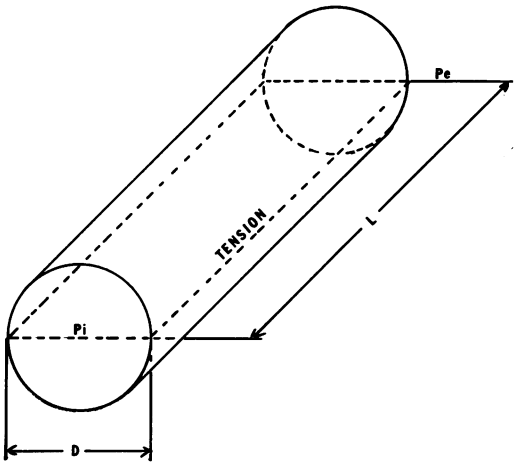

FIG. 2. Diagram illustrating physics theory, "Hoop Tension Principle." [8]

"Therefore it seems to me that what you are achieving by partially covering the aorta in the area of aneurysm with teflon cloth is prevention of first process. In other words, you stabilize the wall of the tube against expansion around three quarters of its circumference and presumably the other quarter of its circumference is securely enough tied to the vertebra that it will not give. Consequently, you prevent the development of dangerous level of hoop-tension. It seems to me therefore that your surgical procedure has a sound basis of explanation and I would be inclined to believe that you will continue to observe success providing that you can satisfactorily fix the partially covering teflon cloth in such a way that it will prevent the expansion of the aorta."

Following a successful "bonding" of the teflon on the adventitia of dogs and supported by a workable physical theory (Hoop principle) as advocated by Dr. Merrill, 40 external grafts were applied to aortic aneurysms meeting the criteria of operability mentioned above. It was reasoned that if the aneurysm had not ruptured at the time of operation and if it could be contained without further expansion, there would be a good chance that rupture might be avoided.

In some patients poor runoff was caused by calcified narrowed vessels incapable of accepting a graft or of providing adequate flow to maintain patency of a graft. In such an instance collateral flow by lumbar or inferior mesenteric vessels with decreased flow in iliac vessels maintained the lower extremities. Interfering with collateral vessels was disastrous as illustrated in a 57-year-old man with a painful abdominal aortic aneurysm associated with pulmonary emphysema, coronary arterial disease, claudication and other disorders. At operation, he not only had calcified small iliac and femoral vessels, but also an anomalous renal artery arising from the aneurysm. It was believed that the advantage of aortic replacement was outweighed by the dangers of resection. Accordingly, the aortic aneurysm was enclosed almost completely with teflon knitted fabric. The following day, the aneurysm ruptured and was resected. A limb was sewn from the graft to the anomalous renal artery. Subsequently, though the extremities survived, symptoms continued and the left colon mucosa partially sloughed. There was loss of neural control of the bladder and rectal sphincters, and almost intolerable ischemic neuritic pain in the perineum. Neither he nor his physicians believed that operative replacement of the aorta was beneficial during the 3 years he survived prior to a death from coronary artery occlusion.

In other patients, there were multiple aneurysms above and below the renal arteries, in the common iliacs, both external and internal iliac arteries, and at times in the femoral arteries. In these poor risk patients, the terminal aortic aneurysms were believed most likely to rupture and were

covered almost completely with an external teflon graft. In one patient, it was necessary to reoperate 2 years later and enclose an enlarging painful aneurysm of the common iliac artery. At the time of this second operation, the aortic aneurysm appeared controlled and the old overlay graft was inseparable from the aortic wall.

Another group of patients had painful, visible, pulsatile aneurysms which were considered emergencies. After sedation, however, such aneurysms would become no longer palpable. At operation, these aneurysms were found to be strong-walled, fusiform, without clot, and usually associated with good runoff vessels. It was believed that containment of expansion was all that was required. This type of patient is illustrated by a 63-year-old woman with a visible and palpable painful aneurysm. After sedation the aneurysm disappeared only to reappear several days later. During an operation for biopsy of a breast lesion, before anesthesia, the aneurysm could be seen and felt, but it disappeared under anesthesia, then reappeared and became tender after the operation. At subsequent operation a fusiform aortic aneurysm 3 cm. in diameter, with normal thickness of walls and no other aortic lesions was found. The aorta was freed and enclosed with teflon cloth. There has been no recurrence of the painful, pulsating mass.

Patients who developed cardiac arrhythmias during trial clamping and declamping of the aorta all had advanced coronary artery disease. This is illustrated by a 70-year-old man who had had multiple coronary artery occlusions and was a class IV risk. At operation after the aorta proximal to the aneurysm was freed and the aneurysm was found resectable, a clamp was applied to temporarily occlude the aorta. With the accompanying rise in blood pressure, ventricular tachycardia ensued. This resolved to normal rhythm after the clamp was slowly released. Clamping and declamping resulted in repetitions of the arrhythmia. Accordingly, it was elected to partially enclose the aneurysm with teflon cloth rather than risk a fatal arrhythmia. About one year later, the patient developed flank pain, and while in another city, the aneurysm was resected. He died of cardiac failure and at autopsy, the cause of the pain was believed to be pyelonephritis and the cause of death coronary artery disease.

Procedure

Since in all instances it was anticipated that the aneurysms would be resected, midline incisions were made from the zyphoid to the pubis. After exploring intraperitoneal spaces, the posterior peritoneum was divided in the midline and parallel to the long axis of the length of the distal aorta. Following examination of the aneurysm and proximal and distal vessels, an encircling tape was passed around the aorta just distal to the origin of the renal arteries. The iliac vessels were exposed as far as necessary for assessment and when indicated, the femoral vessels were exposed in the femoral triangles. After consultation with the anesthesiologist, the patient was categorized as to fitness for resection and as to operative risk. A clamp was placed across the aorta proximal to the aneurysm, when possible, and blood pressure and cardiac rate and rhythm were monitored before and after release of the clamp. This provided an estimate of the patient's ability to withstand occlusion and release of the clamp. If there were complicating circumstances, an estimate of the patient's probability of survival with resection and replacement was compared to that with external wrapping. At all times, resection and replacement of the diseased vessel was preferred, to any other form of treatment. When replacement of the aneurysm was contraindicated the aorta and its distal limbs were dissected to the lumbar branches of the aorta and circumferen-

TABLE 2. *Cause of Death in 19 Patients Having External Teflon Graft*

Cause of Death	No. Pts.
Rupture:	
At operative site	10 (25% failure)
Another site (autopsy evidence)	2
Heart disease	5
Stroke	1
Carcinoma	1
Total deaths	19 (47.5% mortality)

TABLE 3. *Yearly Survival Rates of Patients Treated by Teflon Wrapping*

Years Observed	Total Patients	Patients Surviving	Patients Expired
0–1	8	3	5
1–2	8	6	2
2–3	10	5	5
3–4	9	5	4
4–5	3	1	2
5–6	1	0	1
6–7	1	1	0
Totals	40	21	19

tially in the iliac vessels. Sterile paper was cut in a pattern so that the proximal aorta, the aneurysm and the iliac vessels would be circumscribed with the material. With this pattern as a guide knitted teflon fabric, 13 mils. in thickness, was trimmed to fit. No sutures were applied since the knitted material becomes fast as fibrous tissue grows through and later reforms beyond the interstices of the cloth. In iliac arteries the entire aneurysm was circumscribed with the graft sewn to itself to obtain a snug fit. Initially the vena cava was incorporated in the wrapping. However, following rupture of an aneurysm into the vena cava 3 years after operation, in subsequent cases the graft was placed against the lumbar arteries between the vena cava and the aorta. The posterior peritoneal incision was sutured close to the peritoneum over the graft material.

Postoperatively all patients were maintained in an intensive care unit until all vital signs had stabilized. Recognizing that rupture was a possibility before the fabric had time to become securely anchored, ample blood for transfusion was kept available and the attending personnel were alert for early signs of rupture.

Results

Of 40 patients operated upon there were 13 who had "run-off" vessels insufficient to maintain patency of a graft replacement. Seven had extensive or multiple aneurysms of the aorta, iliac, and at times femoral vessels. Four had expanding and contracting aneurysms which varied in size, and 16 patients had two or more of the conditions listed. Nine patients responded adversely to anesthesia and manipulation of the aneurysm and resection could not safely be accomplished. All 40 patients were considered poor operative risks because of combinations of hypertensive cardiovascular disease, advanced renal arterial disease, severe coronary artery disease, pulmonary emphysema or combinations of these (Table 1).

Twelve patients died with symptoms of retroperitoneal hemorrhage (Table 2). Autopsy was performed on only three of these patients, but from accounts of the deaths of ten patients, it was presumed that death was due to rupture of the aneurysm which had been treated. In two of the three autopsies performed, the patients had ruptured aneurysms which had not been previously enwrapped by the graft. Such nonrelated rupture may have been the case in other patients who died of retroperitoneal hemorrhage, but because there was no autopsy, ten patients (25%) were considered failures.

Heart disease accounted for the deaths of five patients. In these instances there was either autopsy or sufficient clinical data to support the diagnosis. One patient died from stroke 2 years after operation,

while another died from carcinomatosis 2 years after operation.

In those with ruptured aneurysms, four patients died within the first year and six survived for from 1 to 4 years. Two patients died within the first year from causes not related to abdominal aortic aneurysm and seven patients died from diseases unrelated to aneurysm. The two longest survivors died of acute heart disease 4 years, 10 months and 5 years, 6 months after operation. Both were as active as associated emphysema and coronary artery disease allowed until the time of death and neither showed evidence of expansion of the aneurysm.

There are 21 surviving patients (Table 3) five having lived longer than 3 years, five longer than 2 years, and six longer than one year. These patients are without symptoms relating to aneurysm.

Discussion

Since all of the patients operated upon were poor risks, and had symptomatic aneurysms, it is difficult to make comparative studies with patients who had asymptomatic abdominal aortic aneurysms, or with patients who had elective aneurysm resections. In another series of patients operated upon at this institution, operative mortality for asymptomatic abdominal aortic aneurysms was 2%, for symptomatic 17%, and ruptured aneurysms was 56%.[10] This compares with 15% mortality in nonruptured aneurysms and 59% in ruptured aneurysms reported by Cannon, Van de Water and Barker.[2]

TABLE 4. *Incidence of Age and Sex in 40 Patients Having External Aortic Graft*

Age (Average 64.8 yrs.)	Male		Female	
	Alive	Dead	Alive	Dead
45 to 49	2	0	0	0
50 to 59	3	3	3	0
60 to 69	6	6	4	0
70 to 79	2	8	1	2
Total patients	13	17	8	2

Thirty men and ten women had external teflon grafts applied (Table 4); ages

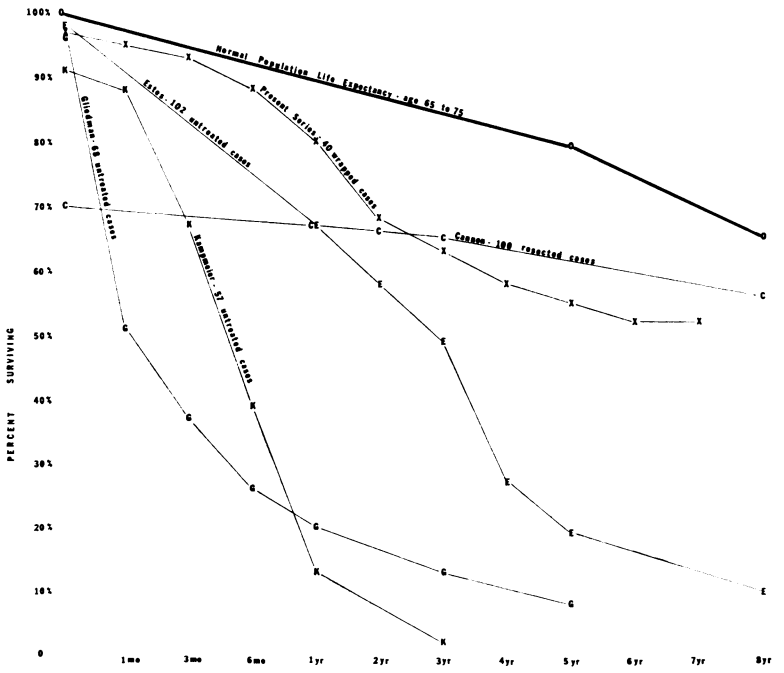

FIG. 3. The normal population life expectancy is shown at the top of the graph in a group of patients between the ages of 65 to 75 as compared to the presently reported group having external aortic graft, 3 groups having no treatment for abdominal aortic aneurysm, and 1 group having had resection of abdominal aortic aneurysm.[2, 5, 6]

TABLE 5. *Summary of Patients Surviving and Having Expired Listed by Categories of Complicating Factors Necessitating External Aortic Graft*

Indications for External Graft	Years Observed**														Totals	
	0–1		1–2		2–3		3–4		4–5		5–6		6–7		Alive	Dead
Poor runoff	1	(2)	3		1		3	(1)		(1)			1		9	(4)
Extensive or Multiple aneurysms		(1)		(1)	1	(2)	1	(1)							2	(5)
Varying-sized aneurysms	1		1		2										4	(0)
Combination* (2 or more of above)	1	(2)	2	(1)	1	(3)	1	(2)	1	(1)		(1)			6	(10)
Total surviving	3		6		5		5		1		0		1		21	
Total expired		(5)		(2)		(5)		(4)		(2)		(1)		(0)		(19)

* In this category, 9 patients were intolerant to anesthesia or procedure.
** ( ) expired.

ranged from 45 to 79, averaging 64.8 years. There were no operative deaths, though in two patients aneurysms ruptured within the first 24 hours after operation. One died and the other subsequently had the aneurysm resected, and survived painfully for 3 years finally succumbing to acute coronary occlusion.

Figure 3 shows the normal population life expectancy (ages 65 to 75) as compared to three untreated groups, one group who had resections,[2, 5, 6] and the presently reported group.

In patients with multiple aneurysms, including thoracic as well as abdominal aorta, iliac (both external and internal) and at times, femoral arteries, two patients survived more than 2 years and four died between 1 and 4 years. Because of a large aneurysm, extending from the diaphragm to both common iliac arteries, one patient was not considered a candidate for the long graft required. The terminal portion of the aneurysm and a part of the upper portion were enclosed with teflon covering. This patient lived 1 year and 3 months before fatal retroperitoneal hemorrhage occurred. Since an autopsy was not done, the site of rupture was not known.

In four patients who had intermittently visible, palpable, and painful aneurysms, there were no deaths and all are surviving without recurrence of symptoms up to 4 years. These patients could have been resected with the expected average mortality of 17%[10] associated with symptomatic aneurysms.

In 13 patients with advanced arterial disease in the runoff vessels, there were four deaths within the first year due to rupture or other arterial disease. Because of extensive cardiovascular disease in these patients, high mortality was anticipated.

While it is commonly accepted that all aneurysms should be resected when feasible; when resection is ill-advised acceptable results can be obtained by using external supportive wrap in properly screened patients.

Summary

A series of 40 patients with abdominal aortic aneurysms were found at operation to have conditions which contraindicated resections of the aneurysms, and were treated by applying teflon fabric externally to the aneurysm.

Prior experiments in 25 dogs showed that teflon cloth became densely incorporated onto the adventitia of the aorta after 3 to 4 weeks, and was tolerated for 6 months without difficulties.

Since tension on the wall of the aneurysm had not produced rupture up to the time of operation, it was reasoned that containment of the tension might prevent future disruption of the aortic wall. Accordingly, these aneurysms were enclosed with teflon knitted material circumferentially, excepting the vertebral attachment to prevent further expansion. Thus tension was controlled according to the Hoop principle, $\left(\text{Tension} = \frac{\text{Pressure} \times \text{diameter}}{2}\right)$.

All patients were considered poor operative risks and all had painful aneurysms. There was one operative death. In a period of 7 years, nine patients died as a result of rupture of the aorta, nine died of nonassociated aging processes, while 21 are surviving without symptoms due to aneurysms (Table 5).

It is emphasized that *this method of treatment is not intended to replace abdominal aortic aneurysm resection,* which is the preferable treatment, but can be used as a substitute method in complicated circumstances.

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