Studies on Dacron Prostheses Treated with Gelatin Sponge : Experimental and Clinical Studies*

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Gelatin-treated, crimped, knitted Dacron prostheses which were neither protein nor plastic were devised in order to obtain low porosity at the time of implantation and to allow high fibroblastic permeability through the interstices as gelatin was absorbed in host tissue. Results of experimental implantation into the abdominal aorta, the ascending aorta, and the inferior vena cava of dogs were satisfactory. Many advantages made the clinical application of the graft possible. The results of follow-up of 13 patients submitted to the graft operation were excellent. It is worth continuing an extensive follow-up study of larger number of patients hereafter.

IT has been shown by research workers that porosity of the synthetic vascular prostheses which are widely used now in clinical medicine is an important factor in the healing process and long-range success of the implanted grafts.¹⁾⁻⁸⁾ The prostheses of low porosity that are knitted or woven too tightly have the advantage that they allow only a small amount of bleeding through the interstices at the time of releasing clamps which permit re-establishment of circulation. Nevertheless, they fail to allow ingrowth of fibrous tissue of the host through the interstices of fabrics to fix securely the internal layer to the prostheses. Then separation of pseudointima may occur as well as calcification of graft wall and degenerative changes of internal layer, probably due to poor nourishment, may occur in the long-range process of tissue organization.⁸⁾ On the other hand, prostheses that are too porous are suited for the purpose of better organization, but they may allow the loss of considerable blood which is at times life-threatening. Another disadvantage is that they could not be used if implantation must be undertaken with the help of extracorporeal circulation which requires heparin. All grafts at the present time are a compromise in respect to the organization and blood loss.

The purpose of this line of investigation is to find an improved graft which consists of both non-absorbable and absorbable components. It was considered that the improved graft must minimize bleeding through the inter-

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stices at the time of implantation but allow high fibroblastic permeability after the absorbable substance sealed into meshes is absorbed in the host.

Kimoto and Wada⁹⁾ used a new type of graft, knitted Dacron graft sealed with plasma-clot or reconstituted collagen devised by the present author. In the previous reports, results of experimental implantation were disappointing in the vena caval replacement,^{9), 10)} although satisfactory in the abdominal aorta.¹⁰⁾ Afterwards collagen derivative, i.e., gelatin, was employed as a substrate in place of reconstituted collagen. Clinical application of the graft has been made possible by the gelatin treatment. Recently, many authors in search for ideal prostheses have reported on the concept and experimental results of a graft that is neither protein nor all plastic. Bascom¹¹⁾ and Jordan et al.¹²⁾ employed gelatin as an absorbable component, while Humphries et al.¹³⁾ used collagen as it was used by us. The prostheses were those of a protein-impregnated type but Wesolowski et al.^{14), 15)} used a compound yarn type.

A clinical evaluation of the compound grafts has not been published. This report includes both experimental results with abdominal aortic, thoracic aortic and inferior vena caval replacement by the crimped knitted Dacron graft treated with fine porous gelatin sponge and the results of clinical experiences.

I. EXPERIMENTAL STUDY

MATERIALS AND METHODS

Preparation of graft treated with gelatin: The coarsely knitted, crimped Dacron graft was rinsed with ethyl-ether and absolute alcohol successively. After drying, it was soaked at 30°C in a 7% solution of gelatin containing methenamin 0.1% until gelatin infiltrated into the interstices of the graft. The solution of gelatin was cooled to 24°C and graft taken out of the solution was freeze-dried. (Freeze-drying was necessary for making gelatin spongy.) During the process of soaking in gelatin solution and freezing, graft was suspended with a small weight on one end so that the crimped wall would be moderately stretched. Baking of the gelatin-sealed graft was accomplished by dry heat for 1 hour at 120°C. The baked graft was suited for immediate use but it was examined to check leaks and lack of uniformity. After autoclaving, the graft was ready for implantation.

Tensile strength and porosity: Tensile strength of the crimped, knitted Dacron treated with gelatin was measured by the Tensilon, a servo-controlled, tensile strength tester.^{16), 17)} Longitudinal and lateral strength were 73 Kg./cm.² and 110 Kg./cm.² respectively. Young's moduli were 2.5 Kg./cm.² 7.4 Kg./cm.² Porosity (expressed by water loss) was 15 ml. per cm.² per min. at a pressure head equivalent to 120 mm.Hg while that of the untreated graft was 6,000 ml.

Replacement of the abdominal aorta: Replacement of the abdominal aorta was performed on 43 mongrel dogs weighing an average of 14.2 Kg. Prostheses implanted consisted of 25 gelatin-treated and as a control 18 untreated ones. They were 8 to 10 mm. in internal diameter and 4 to 5 cm. in length. Dogs were

anesthetized with intravenously injected nembutal of 30 mg. per Kg. of body weight. Grafts were implanted between renal arteries and iliac arteries. Anastomoses were performed by continuous over-and-over suture. Atraumatic Dacron was used as a suture material. All grafts treated with gelatin were implanted without preclotting.

Experimental replacement of the ascending aorta: In 8 mongrel dogs weighing an average of 13.8 Kg., the crimped, knitted Dacron grafts treated with gelatin were implanted into the ascending aorta from the proximity of aortic valves with complete circulatory arrest under profound hypothermia. The grafts implanted were 10 mm. in diameter and 2 to 2.5 cm. in length. The ascending aorta was severed at the proximity of aortic valves and graft was interpositioned between both cut ends. Anastomoses were performed with over-and-over continuous suture by using atraumatic siliconed silk 00000. In one case a continuous mattress suture was employed. Plastic adhesive was smeared on some of these anastomoses. Heparin was administered in a dose of 2 mg. per Kg. of body weight. The methods to induce profound hypothermia which was used in this experiment were as follows; the exsanguination-cooling method with biventricular bypass in 6 cases, the Drew-method without hemodilution in 1 case, and the exsanguination-cooling method with Kay-Cross type rotating disc oxygenator in 1 case. The exsanguination-cooling method is one of the profound hypothermia inducing methods in which at the cooling stage the animal blood is withdrawn and replaced with plasma expander under the extracorporeal circulation and at the rewarming stage this exsanguinated blood is returned into the animal.¹⁸⁾

Inferior vena caval replacement: Eight mongrel dogs weighing an average 15 Kg. were anesthetized by intravenous injection of nembutal 30 mg. per Kg. of body weight. Inferior vena cava was resected and a crimped, knitted Dacron graft which had been treated with gelatin and whose length was 4 to 5 cm. and diameter 8 or 10 mm. was implanted. Anastomoses were performed with over and over continuous suture by using atraumatic Dacron as a suture material.

Methods of observation: Dogs subjected to the abdominal aortic replacement were sacrificed at time intervals of between 1 week and 10 months postoperatively in order to examine how the implanted graft had been organized. Grafts were taken out and then gross and histological examinations were carried out. The excised graft was opened in a fresh state. Internal surface was rinsed with a 5% glucose solution. Silver nitrate impregnation by 0.25% solution was applied to the inner surface of the graft, which was then fixed with 10% formalin solution. A few grafts were silver-impregnated by perfusion method and fixed in situ.¹⁹⁾ With a binocular dissecting microscope the endothelial surface of the inner layer was examined. From specimens prepared as above small areas of the pseudointima were dissected off the inner surface of cloth tube, cleared in xylene and mounted flat. Nuclear staining was sometimes made by Weigert's iron hematoxylin after the dissection. They were examined under a light microscope. Perpendicular sections of grafts were usually stained by the Masson-Goldner method, hematoxylin-eosin stain and Weigert's elastic stain.

In the experimental implantation of the ascending aorta careful observations on the bleeding from the graft were made during, before and after the neutralization of heparin. All dogs subjected to the inferior vena caval replacement were sacrificed about 1 month after the operation because of occlusion demonstrated by venograms. Grafts taken and inspected grossly.

RESULTS

Crimped, knitted Dacron graft treated with gelatin was easily sterilized. It was rigid in dry state but after immersion in balanced salt solution for a few minutes it became softened and was easy to handle. The graft which had absorbed water was similar to a fresh homograft in respect to its touch and elasticity. This prosthesis was easily tailored and sutured. It had less fraying tendency than the untreated Dacron prosthesis.

Replacement of the abdominal aorta: The Dacron graft treated with gelatin was safely implanted without preclotting, but it was almost impossible for untreated one to be used without preclotting. Blood oozing from the wall of the gelatin-treated graft was so small that hemorrhage could be controlled easily by application of slight pressure by gauze. Results are shown in Table I. There was no remarkable difference in the patency rate between the gelatin-treated graft and the untreated one, although the former was slightly greater. In 2 cases gelatin-treated grafts were patent in spite of being surrounded by abscesses. Delayed leakage with hematoma formation around the graft was not a problem. The difference in occurrence of infection was insignificant.

Table I. Results of the Abdominal Aortic Replacement in 43
Dogs Followed for 1 to 10 Months

Grafts	Total	Dead	Thrombosed	Ruptured	Patent	(per cent)
Gelatin-treated	25	5	2	2	16	(64%)
Control	18	4	3	1	10	(55.6%)

Gross findings:—It was impossible to see any substantial differences in gross findings between treated and untreated grafts. In each group during the first or second postoperative weeks, the fibrous connective tissue surrounding the graft was not dense and loosely attached so that it could be easily separated from the graft wall. Connection with the wall was made by the fine fibrous or fibrinous strands. A dark reddish-black membrane of fibrin clot covered the inner surface of the graft treated with gelatin as well as the untreated one in a week or two (Fig. 1). About 3 weeks after the operation dense fibrous tissue became firmly attached to the graft. Fibrous tissue surrounding the treated graft was much thicker. After 3 to 4 weeks post-operatively, white, glistening, thin membrane was observed near both ends, while the inner layer at the center of the graft turned reddish-grey colour. As time passed the white part of the inner layer became larger and spreaded

Fig. 1. Gross specimen of a gelatin-treated graft 2 weeks after implantation into the abdominal aorta of a dog. Note thin membrane of fibrin on the inner surface, and moderately dense fibrous tissue surrounding the graft. Intima of the host aorta stained black by silver-impregnation.

Fig. 2. Gross specimens of a gelatin-treated graft 15 weeks after implantation into the abdominal aorta of a dog. Note thin glistening membrane covering the graft. Larger area is stained black by silver-impregnation.

Fig. 3. Photomicrograph of a specimen dissected away from the inner layer of a gelatin-treated graft 15 weeks after implantation into the abdominal aorta of a dog. Note mosaic pattern of endothelial lining. Under endothelial sheet, plastic fibers are seen. Silver-impregnation. Original magnification: $\times 48$

toward the center. Three to 4 months after the implantation the inner surface of the graft was covered with this white firm membrane to almost its entire length (Fig. 2). One remarkable finding that was noticed in the gelatin-treated graft was that the inner layer covering the graft was thinner and firmer than in the untreated one.

Endothelium lining the graft:—Endothelial cells were observed on the surface of the internal membrane (Fig. 3). In the early days of the postoperative period they usually appeared near both ends. The epithelial sheet that they

formed was continuous with the endothelium of the host aorta over the anastomotic line. But the mosaic patterns that were demonstrated by silver impregnation were different in both cases. The shapes of the endothelial cells lining the graft were not so much elongated as polygonal, thus resembling the endothelial cells in vitro as described in the previous report.²²⁾ Multinucleate cells, especially binucleate cells, were frequently observed (Fig. 4). Mitotic division could not be found. Areas of endothelial covering varied with the specimens. Some grafts obtained 3 weeks after operation even showed nearly complete covering by endothelium. Nevertheless, in others the endothelial cells were scarce at the center of graft. Graft implanted for more than 4 months showed nearly perfect endothelialization. There were no remarkable differences between both groups of grafts. A comparison of speeds in endothelial lining could not be made.

Fig. 4. Photomicrograph of the endothelial cell lining the graft. Note a binucleate cell and less elongated shapes of endothelial cells. Silver-impregnation, Weigert's iron hematoxylin. Original magnification: $\times 320$

Perpendicular sections of grafts:—An ingrowth of fibrous connective tissue interstices was noticed in 2 week postoperative specimens. In the 4 week specimens, ingrowth became more intense and the gelatin was almost absorbed and replaced by the connective tissue element (Fig. 5). Minimal tissue reactions were noticeable as compared with that of an untreated graft. Both smooth muscle cells and elastic tissue could not be perceived in the layers composing the graft wall. The healing process of the gelatin-treated graft progressed like that of the untreated one: it was neither delayed nor promoted. Absorption of gelatin gradually took place as fibrous tissue invaded the interstices.

Implantation into the ascending aorta: The results obtained from 8 dogs which were operated upon for the ascending aorta with gelatin-treated grafts are shown in Table II. Five of 8 cases resulted in operative death. The causes of death were due to air embolism of the coronary artery in 2

cases; bleeding from tears of aortic wall at the anastomotic site in another 2; and stenosis of the graft which was induced by the plastic adhesive in 1. Three surviving cases died 20, 5, and 3 hours after the operation from respiratory failure. Perfusion and total circulatory arrest were also considered

Fig. 5. Photomicrograph of a perpendicular preparation of the gelatin-treated graft 4 weeks after implantation into the abdominal aorta of a dog. Note fibroblastic ingrowth through the interstices. Gelatin is not seen. Hematoxylin-eosin stain. Original magnification: $\times 48$

Table II. Results of Experimental Implantation of the Gelatin-Treated Graft into the Ascending Aorta with Total Circulatory Arrest under Profound Hypothermia

Method of hypothermia	No. of case	Total circulatory arrest		Total blood loss after implantation	Rewarming stage			Prognosis	Causes of death
		E.T.*	Duration		Cardiac resuscitation	Spontaneous respiration	Reflex		
Exsanguination cooling method with biventricular bypass	1	6.8-15	95		Yes	Yes	Yes	Operative death	Stenosis of graft
	2	7.5-14	60	1,000	Yes	Yes	Yes	Death, 20 hrs. postop.	Respiratory failure
	3	10-14	73	1,200	Yes	Yes	Yes	Death, 5 hrs. postop.	Respiratory failure
	4	9.8-15.2	90		No	No	No	Operative death	Coronary embolism
	5	7.5-14.5	45	2,000	Yes	Yes	Yes	Operative death	Bleeding at anastomoses
	6	5.9-10	58	2,000	Yes	Yes	Yes	Operative death	Bleeding at anastomoses
Exsanguination Sealy method	7	9.4-13.2	53	280	Yes	Yes	Yes	Operative death	Coronary embolism
Drew method	8	8.2-15.4	62	500	Yes	Yes	Yes	Death, 3 hrs. postop.	Hemothorax

* E.T.: Esophageal temperature

as factors which influenced their death. In Fig. 6 is shown the operative and postoperative course of the case that endured the longest survival. In respect to the hemorrhage from the graft wall, 1 case without hemodilution showed scarcely any blood loss, while in cases perfused with hemodilution, a moderate amount of bleeding was observed immediately after circulation was re-established. Nevertheless, the bleeding decreased gradually as the circulating blood became concentrated. The condition was satisfactory after heparin was neutralized. There was no loss at 120 mm.Hg.

Vena caval replacement: The results are summarized in Table III. There

Fig. 6.

Table III. Results of the Inferior Vena Caval Replacement Using Gelatin-Treated Dacron Graft

Dog	Duration, days	Patent	Thrombosed	Suture line constriction	Formation of neointima
911	43	No	No	Yes	No*
918	36	No	No	Yes	Yes
919	35	No	No	Yes	Yes
1003	31	No	No	Yes	Yes
1009	32	No	No	Yes	Yes
1010	31	No	No	Yes	Yes
1011	31	No	No	Yes	Yes

* Abscess formation.

were no grafts that remained patent. Occlusions were shown at the site of the anastomoses. The grafts were neither collapsed nor thrombosed. The patent lumen of the graft did not contain fluid, and pseudointima-like membrane covered the inner surface except 1 case in which the graft remained uncovered and contained pus.

DISCUSSION

Why gelatin was used: As in the previous report,²⁰⁾ the author found that reconstituted collagen was an excellent substrate for endothelial growth in sheet in tissue culture. The knitted Dacron grafts sealed with the reconstituted collagen that we employed in the experimental replacement were better suited for arterial use than for venous use. Reconstituted collagen is closely similar to normal tissue collagen and considered ideal as a substrate. Dunphy²¹⁾ also pointed out the possibility of an ideal graft composed partly of collagen, with some tendency to mold and alter its shape in accordance with stress. Nevertheless, collagen cannot be obtained easily at present. The commercially sold collagen is expensive, and procedures to reconstitute collagen in a sterile condition are complicated. For these reasons, collagen-treated Dacron prostheses are not suitable for ordinary vascular reconstructive surgery. Accordingly, gelatin was used in place of collagen. By this change both preparation and sterilization of the gelatin-treated graft were made easy and secure. Gelatin foam of fine pore was employed so that absorption might progress quickly and well-organized healing of the graft could be achieved. Gelatin sponge is also commonly used in tissue culture as a substrate for organized or differentiated culture.²²⁾ Florey et al.^{19), 22)} demonstrated elastin and smooth muscle cell in the wall of the implanted graft by electron microscopy. At present, structures which resemble that of a normal blood vessel wall have not been reportedly obtained by light microscopy.

Advantages and disadvantages of gelatin-treated graft: The crimped, knitted Dacron graft treated with gelatin sponge has the advantages that are described as follows: There was scarcely any blood loss through its wall when the circulation was re-established. With its good adaptability, ease of tailoring, and lack of fraying tendency it could be safely implanted without preclotting even when heparin was administered. Gelatin was absorbed in the host body very quickly and the high porosity that was obtained by absorption permitted even more fibroblastic ingrowth through the interstices. The graft was well organized after implantation and the inner layer of the graft was thinner and more firmly attached to the wall. On the other hand, the disadvantages in this method were: In dry state, gelatin was easily cracked by force. The graft

could not be washed and used again once it was contaminated with fluid. Repeated autoclaving made the graft more rigid and produced more cracks.

Grafts reported in the previous reports: Vascular reconstructive surgery by synthetic vascular prosthesis has come to be one of the standard procedures since woven or knitted Dacron and Teflon graft has been manufactured. Fundamental problems confronting the vascular graft have been relatively settled in recent years, although porosity is one of the problems which has not been solved.²⁴⁾ Though some workers doubt the necessity of the porous wall of vascular prostheses,²⁵⁾⁻²⁸⁾ it is considered to be an important factor in the success of the implanted graft.¹⁾⁻⁸⁾ Porosity is closely related with the blood loss at the time of implantation as well as with the organization of the graft. Therefore, definite conclusion has not been reached as to how porous the graft should be. According to Wesolowski,³⁾ the porosity of the synthetic vascular graft which widely prevails at present, would appear to be inadequate to avoid septum formation and calcification. Recently devices are reported to improve the graft so that it may possess a low implant porosity which increases by resorption of absorbable component to attain a higher porosity for organization. Wesolowski^{14), 15)} preferred the compound yarn type rather than the coated. Kimoto and Wada,⁹⁾ Humphries et al.,¹³⁾ and Maruyama et al.¹⁰⁾ used a collagen-coated type, while Bascom²²⁾ and Jordan et al.¹²⁾ used a gelatin-coated. The results of experimental implantation of these grafts were promising. Usually in many of these cases, resorption of the collagen derivatives took a great deal of time in host tissue and much attention should have been paid to the nature and character of the absorbable substances in order not to delay the organization. In this experiment great care was taken in order that absorption could progress quickly. The fine, porous sponge of the gelatin provided good absorption, and blood loss through its pores could be controlled to such an extent as to allow implantation even when heparin was used.

Formation of endothelial lining: The basis on which cells lining the inner surface of the graft were identified with endothelial cells in this experiment is as follows: Silver-impregnation showed that cell boundaries were characteristic of epithelial cells. Though they differed in shape from endothelial cells of the host aorta, they were quite similar to the pure endothelial cells in vitro,²⁰⁾ especially those on collagen film, in all morphological characteristics. The origin of the endothelial cell lining the graft could not be ascertained in this experiment. The formation of endothelial lining at the middle portion was delayed, and the endothelial sheet was continuous over the anastomotic line. Though transformation between endothelial cells and fibroblasts are still in debate,²⁹⁾ according to the author's observations in vitro, it was rare that an

endothelial cell turned into a fibroblast-like cell. It is considered that endothelial cells are a highly specialized epithelial cell. Then it is postulated that formation of the endothelial lining of the graft is accomplished by the host endothelium, whether it is of aortic or capillary origin. But the author would rather think that the endothelial lining was made by the extension of endothelium from both anastomoses.

In this experiment, formation of the endothelial lining could be completed as Florey et al.,¹⁹⁾,²³⁾ Jordan et al.,³⁰⁾ Stump et al.,³¹⁾ and Poole et al.³²⁾ reported. Difference in age, animal, and prosthetic vascular graft should affect the extent of endothelialization. According to Mackenzie and Loewenthal,³³⁾ the endothelial growth appeared to be independent of the organization of underlying fibrin. Nevertheless, if the good effect of collagen as a substrate is taken into account, the endothelial lining would progress to cover a graft with support of fibrous connective tissue. Such supporting tissue is readily available at the ends of the grafts and this may also affect the speed of the endothelial growth.

Implantation into the ascending aorta: For the purpose of reconstructive surgery of the ascending aorta, profound hypothermia with total circulatory arrest might not be necessary. But this procedure was employed as a preliminary experiment so that resection and grafting of the whole aortic arch should succeed in the near future without attempting to use a temporary bypass. Reconstruction of the aortic arch or ascending aorta with total circulatory arrest has not been reported.

II. CLINICAL EXPERIENCES WITH CRIMPED, KNITTED DACRON GRAFTS TREATED WITH GELATIN SPONGE

On the basis of the satisfactory results of experimental replacement, the crimped, knitted Dacron graft sold commercially as "Tetrol", was treated with fine porous gelatin sponge for the purpose of clinical use, as described in the method of experiment. It has been employed almost exclusively since March, 1963, for the arterial reconstructive surgery. It has proved entirely satisfactory in the treatment of aortic and to a less extent, of peripheral vascular lesion requiring arterial replacement. The purpose of the following report is an up-to-date follow-up of patients in whom the graft was used for the treatment of vascular lesion.

CLINICAL MATERIALS

The arterial reconstructive surgery was performed in the treatment of 13 patients seen between March, 1963 and April, 1964 (Table IV). The patients con-

Table IV. Results of Operations Using Dacron Grafts
Treated with Gelatin

Disease	Total cases of patients	Early results		Late results	
		Death	Success	Death	Success
Coarctation of aorta	5	—	5	—	5
Aneurysm of abdominal aorta	4	—	4	—	4
Aortoiliac and/or femoropopliteal occlusive disease	3	—	2	—	2
Iliac arteriovenous fistula	1	—	1	—	1
Total	13	—	12	—	12

sisted of 5 cases of the coarctation of the thoracic aorta, 4 cases of aneurysm of the abdominal aorta (one of which had been ruptured), 3 cases of thrombo-obliterative disease of the distal aorta, and of the iliac, femoral, and popliteal arteries, and 1 case of arteriovenous fistula. The coarctation contained 1 preductal type; 2 postductal type; and 2 atypical cases.

OPERATIVE TECHNIQUES

The method of operation was dependent upon the nature and extent of the disease. To most of the coarctation of the aorta excision of the diseased segment and graft replacement were employed (Table V, Case 1-4) by the use of spinal fluid drainage.³⁶⁾ But in one of the cases of atypical coarctation, the bypass graft of the descending aorta was employed (Case 5). Aneurysm of the abdominal aorta was mostly excised and bifurcated graft was implanted. Distal anastomosis was end-to-end or end-to-side according to the status of iliac arteries. In 1 case (Case 9), the aneurysmal sack was opened, thromboendoarterectomized, and the implanted graft was covered by the posterior wall of the sack.³⁷⁾ For the treatment of aortoiliac and/or femoropopliteal occlusive disease, bypass graft was employed (Table VI). All 3 patients underwent the combined lumbar sympathectomy. The right iliac arteriovenous fistula was excised and the graft was implanted between the abdominal aorta and the right iliac artery while the venous wall was closed by continuous suture.

METHOD OF OBSERVATION

At the time of operation, bleeding through the wall of the graft when the clamps were released was watched carefully. In the cases of coarctation of the aorta, intraluminal pressure curves were described by the transducer whenever possible. The 13 patients submitted to the graft operations were observed for a period of from 1 month to 1 year and 2 months. The follow-up was obtained by personal examination and by communication with the patient and the referring physician. The graft was considered open and operative success maintained when the information obtained indicated that the patient was alive and free of ischemic symptom and if the pulses could be palpable distal to the region of operation. Aortography and X-ray film of the chest or abdomen were also taken in some cases.

RESULTS

Coarctation of the aorta: All 5 patients submitted to the operation for the coarctation survived the operation and were discharged with functioning grafts without complication (Table V). The pressure gradient across the stenosed segment almost, if not completely, disappeared. Postoperative pres-

Table V. Clinical Cases Operated upon with Gelatin-Treated Dacron Grafts

NO OF CASE	AGE · SEX	DISEASE	OPERATIVE TECHNIQUE	SIZE OF GRAFT	RESULT · FOLLOW-UP	COMMENT
1	21 F	Aneurysms and Coarctation of Thoracic Aorta	Excision Graft Replacement	16 mm. diameter 100 mm. length	Excellent 1 yr. 2 mos.	Coarct. Atypical, Membranous
2	25 M	Coarctation (preductal) P.D.A., V.S.D.	Excision Graft Replacement	19 x 130	Excellent 1 yr.	VSD: closed by 2nd Op.
3	22 M	Coarctation (postductal)	Excision Graft Replacement	19 x 90	Excellent 5.5 mos.	with Aneurysm of Innominate Art.
4	25 F	Coarctation (postductal)	Excision Graft Replacement	16 x 50	Excellent 4 mos.	with Turner's Syndrome
5	21 F	Coarctation (atypical)	Bypass Graft	16 x 160	Excellent 1 mo.	Coarct. Elongated
6	54 F	Aneurysm of Abdom. Aorta	Excision Graft Replacement	16 x 120	Excellent 8 mos.	Hypertension, Old Myocardial Infarction
7	61 F	Aneurysm of Abdom. Aorta	Excision Graft Replacement	16 x 70	Excellent 6 mos.	Ruptured
8	53 F	Aneurysm of Abdom. Aorta	Excision Graft Replacement	16 x 110	Excellent 1.5 mos.	Renal Insufficiency
9	59 M	Aneurysm of Abdom. Aorta	Endarterectomy, Graft covered by poster. Sac	16 x 100	Excellent 1 mo.	

(To be continued)

Table VI. Clinical Cases Operated upon with
Gelatin-Treated Dacron Grafts

NO OF CASE	AGE SEX	DISEASE	OPERATIVE TECHNIQUE	SIZE OF GRAFT	RESULT FOLLOW-UP	COMMENT
10	57 M	OCCLUSION OF AORTA & ILIAC ARTERY	Thrombectomy Bypass graft Sympathectomy	8 mm. Diameter 120 mm. Length - 8 X 450	Excellent 2 mos.	Distal graft: implanted at the 2nd operation
11	59 M	OCCLUSION OF LEFT ILIO- FEMOROPUPLI- TEAL ARTERY	Thromboendo- arterectomy Bypass graft Sympathectomy	6 X 550	Poor 1 mo.	Early throm- botic occlu- sion, Serum hepatitis
12	52 M	OCCLUSION OF RIGHT ILIAC ARTERY	Bypass graft Sympathectomy	8 X 180 6 X 450	Good 1 mo.	Distal graft: implanted at the 2nd operation one day after the 1st one
13	45 M	ARTERIOVENOUS FISTULA OF RIGHT ILIAC ARTERY & VEIN	Excision of fistula with iliac artery Graft Closure of venous wall	8 X 130	Excellent 1 mo.	With aneurysm

(Concluded)

sure curve tracing just distal to the lower anastomosis showed the characteristics of the normal aorta (Fig. 7). The patient in case 2 was successfully operated upon for the associated ventricular septal defect under the direct vision 8 and half months after the operation for coarctation and patent ductus arteriosus. The patient in case 4 was associated with Turner's syndrome which was confirmed by the exploratory laparotomy and sex chromosome demonstration. Case 3 had an aneurysm of the innominate artery which remains to be operated. Both in case 1 and 5, coarctation was located in the unusual site. The former had a short segment of coarctation, but in

Fig. 7. Simultaneous recording of pressures and contours of pulse waves in proximal and distal portions of coarctation of the thoracic aorta in a female patient (Case 5). Notice postoperative elevation of systolic and diastolic pressure near the distal anastomosis. Contour shows the characteristic dicotic notch.

Fig. 8. Case 1. Preoperative angiogram showing the aneurysm of the descending aorta. The distal aneurysm cannot be seen clearly probably due to the coarctation between them.

the latter there was an elongated coarctation. All the patients were alive in the postoperative period of 1 month to 1 year and 2 months. The graft functioned well, showing no sign of stenosis (Figs. 8 and 9). There could not be found any calcification of the graft wall on the X-ray films.

Abdominal aortic aneurysm: The results are shown in Table V. There was no operative death, though patients of advanced ages, often had other degenerative lesions such as old myocardial infarction (Case 6), and renal insufficiency (Case 8). In case 7 the aneurysm had ruptured. The postoperative course was uneventful and patients were discharged showing complete recovery. The follow-up of 1 to 8 months showed that the patients lived

Fig. 9. Case 1. Postoperative retrograde aortogram taken 1 year and 2 months after the operation. Graft is patent and there is no irregularity on its contour.

with the functioning graft (Figs. 10 and 11).

Occlusive disease of the aorta and of the iliac, femoral, and popliteal arteries:

All 3 patients submitted to graft operation for thrombo-obliterative disease survived operation. The results varied with the type of operation and the extent of the disease (Table VI). The patient (Case 10) submitted to bypass graft for aortoiliac occlusive disease was reoperated 7 hours after the first operation because of thrombus formation at the anastomotic site of the left iliac artery. After thrombectomy was performed, a bypass graft was anastomosed to the left iliac graft and the left popliteal artery. The grafts func-

Fig. 10. Case 7. Preoperative translumbar aortogram showing the aneurysm of the distal portion of the abdominal aorta.

Fig. 11. Case 7. Postoperative translumbar aortogram taken 6 months after the operation. Graft is patent.

tioned well and he was discharged without complication. Follow-up study indicated that the symptom of the lower extremities had markedly improved. To the patient (Case 11) with left ilio-femoro-popliteal occlusive disease, a long bypass graft was implanted. Lesions were considered to be thromboangitis obliterans. Thrombotic occlusion of the graft was demonstrated during the early postoperative days. Reoperation was deferred because hepatitis ensued. The third patient (Case 12) was operated upon for the occlusion of the right iliac artery. But thrombotic occlusion at the site of distal anastomosis was found 24 hours after the operation. A bypass graft was anas-

Fig. 12. Case 13. Translumbar aortogram taken 1 month after the operation. Graft is patent. The right iliac and femoral circulation is maintained normally. There is no arteriovenous fistula.

tomosed to the distal portion of the previous bypass graft and to the right popliteal artery. He was discharged with functioning grafts. His condition of the right lower extremity was good.

Arteriovenous fistula: One patient operated upon for the iliac arteriovenous fistula maintained the function of the graft (Fig. 12). The arterial pulsation of the right lower extremity was restored.

COMMENTS

The reports on the clinical experience of the graft have not been published. It may be too early to evaluate from these experiences the clinical usefulness of the crimped, knitted Dacron graft treated with gelatin sponge, because clinical cases are not many, no graft material has been recovered, and a long-term follow-up study is a problem in future. But from both a technical and functional point of view, it has proved satisfactory in the treatment of aortic and peripheral vascular lesions and especially in aortic lesions.

The advantage to treating the graft with gelatin is that it allows only a small amount of bleeding after releasing the clamps. It is desirable for the replacement of the thoracic aorta which necessitates a large amount of bleeding even if preclotting was done and which favours the fibrinolytic phenomenon. The graft may be also suitable for replacement by using cardiopulmonary bypass techniques with administration of heparin. It could be safely employed for the treatment of aneurysm of the abdominal aorta in a poor risk patient as well as a good risk patient. Hemorrhage often gives deterious effect to the patient with abdominal aortic aneurysm because, in most instances, of other degenerative changes in the body.

Disappointing results were obtained from an operation for the treatment of peripheral vascular lesion. Among the factors contributing to failure in the immediate result were the nature and extent of the disease, and the choice of operative technique. It is considered that the graft would be suitable for the peripheral lesion, if the inner layer of the graft in the experiment is taken into account.

It is worth doing an extensive follow-up study of a large number of patients submitted to the graft operation, and late morphological changes as related to long-term patency are some of the problems which requirue further investigation.

SUMMARY

(1) Coarsely knitted crimped Dacron prostheses were treated with gelatin sponge with fine pores in order to obtain low porosity at the time of

implantation and to allow high fibroblastic permeability through the interstices of fabrics as gelatin was absorbed in host tissue.

(2) The grafts were used in the experimental replacement of the abdominal aorta in 25 dogs, in the implantation of the ascending aorta under profound hypothermia with total circulatory arrest in 8 dogs, and in the inferior vena caval (infrarenal) replacement in 8 dogs. As a control, the untreated grafts were implanted into the abdominal aorta in 18 dogs.

(3) In the abdominal aortic replacement, there was no remarkable difference between the patency rate of the gelatin-treated grafts and that of the untreated ones. The inner surface of the graft was covered with thin and smooth membrane, and the outer coat of fibrous tissue adhered firmly to the graft. Histologic study revealed no delay of organization of the graft. In 3 to 4 weeks, there was nearly complete absorption of gelatin which allowed fibroblastic ingrowth through the interstices. The inner layer of the graft could be lined with the endothelium to its entire length.

(4) Of 8 dogs submitted to the implantation into the ascending aorta, 4 survived operation. The graft could be used safely even though heparin was administered.

(5) There were no patent grafts which were obtained from the inferior vena cava.

(6) Advantages and disadvantages of the gelatin-treated graft and importance of this kind of graft that is neither plastic nor protein were discussed.

(7) The gelatin-treated grafts were applied for clinical use in the treatment of 5 cases of the coarctation of the aorta, 4 cases of the abdominal aortic aneurysm, 3 cases of occlusive disease, and 1 case of arteriovenous fistula. Patients were followed for a period of 1 month to 1 year and 2 months. It had been proved entirely satisfactory in the treatment of aortic and to a less extent, of peripheral lesions.

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