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FIG. 1.—Orlon replacing portion of abdominal aorta of dog. Carrel suture used (see text).

ARTERIAL REPLACEMENT BY "ORLON" CLOTH*

A PRELIMINARY REPORT OF ITS EXPERIMENTAL AND CLINICAL USE

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During the years since the second world war it has gradually become clear that the grafts used as substitutes for arteries served chiefly as scaffolding on which the tissues of the host developed a new vessel. The survival of cells from the donor has not proved essential for success. Indeed, good results may be obtained where no effort is made to maintain the viability of the cells of the graft. K. Nakayama (1953, personal communication) has used human homografts preserved in alcohol to replace the aortic bifurcation. In our own hands the results with heterografts sterilized and preserved in neutral formalin and used in animals have been most satisfactory over considerable periods of time. It therefore seemed a logical consequence that artificial materials might be used as a scaffold, and Voorhees and his colleagues (1952) reported the successful use of an inert plastic cloth, "vinyon-N."

Experimental Studies

Vinyon-N was difficult to obtain in England, and so we chose for trial "orlon," a plastic developed by duPont and available in Great Britain from Zurrer Silks (Darwen) Ltd., Anchor Mills, Darwen, Lancs. It was one of a variety of woven plastic materials which were easily available and likely to be chemically inert in the body. The choice was made chiefly on the naked-eye appearance of the weave and its power to hold sutures. Its ability to prevent excessive leakage of water or blood through its pores was also tested on the laboratory bench before it was used surgically. It was found to be more suitable in these ways than other materials that were tried.

Orlon is an acrylic resin, a polymer of acrylonitrile, and possesses the qualities of strong resistance to acids, alkalis,

salts, and greases. The fabric used was 175 on the weft and 260 on the warp. It was inelastic, soft, and pliable, and sewed easily without tearing.

Mongrel or greyhound dogs were anaesthetized with intravenous pentobarbitone sodium, and under aseptic conditions the peritoneum was opened through a long midline incision. The posterior peritoneum was incised, exposing the distal abdominal aorta, the lumbar arteries were ligated, and 2 to 3 cm. of aorta was resected after Blalock clamps had been applied

to it above and below. The tube of orlon fabric was then sutured end-to-end to the aorta with over-and-over continuous stitches of 5/0 silk moistened with liquid paraffin, and the clamps were temporarily removed to allow blood to fill the tube and test for leaks at the anastomoses. Blood oozed through the orlon fabric for about a minute while clotting was occurring in the interstices of the fabric.

FIG. 2.—Aortogram two months after insertion of orlon. Carrel suturing not used. The upper anastomosis (arrow) is barely discernible, the lower is located by the small notch.

Animal Studies with Orlon

Dog No.	Type of Anastomosis	Result	Time (Weeks) and Method of Check	Total Time Followed (Weeks)
G.2	End-to-end	Patent	12 Necropsy	12
G.3	"	Ruptured anastomosis	16 "	16
G.4	"	Patent	21 Aortogram	21*
G.6	"	"	3 " "	
			15 Clinical	15*
G.7	"	"	8 Aortogram	
			16 Clinical	16*
G.9	End-to-side	"	4 Aortogram	
G.10	End-to-end	"	8 Necropsy	8
			10 hrs. "	
G.11	Side-to-side†	Thrombosis	3 Aortogram	
			5 Necropsy	5
G.12	"	Patent	4 Clinical	4*

* Indicates animal still surviving for further study.

† All prostheses were inserted in the aorta, except in G.11 (aorta to external iliac).

*Based on a communication to the Surgical Research Society, London, November 26, 1954.

FIG. 3.—Interior of orlon tube inserted end-to-side two months previously. The interior of the host aorta is visible at either end, and that of the orlon, covered by transparent new "intima," in the centre.

FIG. 4.—Microscopical section ($\times 55$) of orlon and collagen four months after insertion. Spaces near the orlon are artefacts. The thickness of collagen is greater on the exterior (see text).

When the oozing through the fabric had stopped the clamps were removed and blood was allowed to flow through the orlon tube (Fig. 1).

In some experiments (G.9, G.11, and G.12 in the Table) a shunt made of orlon was used to conduct the blood around an artificial aortic block produced by tying the aorta. The tubes of orlon were anastomosed end-to-side or side-to-side to the aorta, in which an oval window had been cut to make the aortic stoma larger. These end-to-side and side-to-side anastomoses were tried because they made

possible a larger stoma than would end-to-end anastomosis, in which the stoma would, of course, be limited to a diameter equal to that of the host artery. A large stoma, and particularly one in which the suture line did not completely encircle the host vessel, should be less liable to closure by thrombosis. The end-to-side and side-to-side anastomoses worked well in the aortas of dogs in which they were tried.

The posterior peritoneum was closed over the prosthesis and the abdomen closed in layers. Penicillin and "plasmosan" were given post-operatively. At a later date patency of the grafts was determined by an aortogram performed by injecting diiodone into the aorta above the prosthesis through a cardiac catheter which had been passed down into the aorta from the common carotid artery (Fig. 2).

The results in the dogs which had orlon prostheses are shown in the Table. The prostheses were implanted in their abdominal aortas or as shunts around an aortic or iliac obstruction. One (G.10) died 10 hours after operation without recovering from the anaesthetic. The prosthesis was patent and lined internally by smooth fibrin. The anastomosis was intact. Another (G.3) died at 16 weeks post-operatively from rupture of a false aneurysm that was surrounding the prosthesis and which had formed from an anastomotic leak. The orlon tube was floating in the centre of the false aneurysmal sac and had no fibrous reaction within or around it. The significance of this lack of reaction

is discussed below. The suture material was found to have pulled out of the aorta at the distal anastomosis. In one animal (G.11) a 5-in. (12.5-cm.) long shunt had been placed from the aorta to the left common iliac artery, bridging a tape ligature on the iliac artery. The shunt thrombosed in the early post-operative period, and on sacrifice at four weeks the graft was found to be thrombosed and one of the distal anastomotic sutures had constricted the iliac artery. All the other orlon prostheses have remained patent. The two failures were due to technical errors which were in no way peculiar to the material or the method.

The tubes become lined with a smooth glistening layer of hyaline collagenous tissue, the innermost layer indistinguishable from intima (Figs. 3 and 4). They are surrounded by a thick layer of fibrous tissue which encases and grows into the meshes of the cloth (Fig. 5). They are tolerated without ill effect. The collagen lining and surrounding the tube results from the vascularity and activity of the surrounding tissues. This was well shown in dog G.3. Rupture of the distal suture line occurred soon after operation, and blood continued to flow through and around the tube and into the false aneurysmal sac, in which it lay almost free for several months before death. Despite this, the orlon tube looked almost as fresh as when it was inserted. There was a little fibrin deposited on it, but no collagen formation whatever. This suggests that contact with surrounding living tissues may be necessary for the collagen to form. Mere contact with circulating blood is insufficient.

Another interesting point that emerged at necropsy was the way in which the orlon retained its strength. After several months in the tissues the tensile strength of the fabric appeared to be quite unchanged. This is of great practical importance, because mere unsupported collagen would be expected to stretch under pressure and with the passage of time.

None of the prostheses and their surrounding tissues have shown evidence of calcification on x-ray examination.

Clinical Application

Encouraged by these results, we placed orlon tubes in three patients. Brief case summaries are presented.

Case 1

A 58-year-old male Civil Servant was admitted to St. Bartholomew's Hospital complaining of epigastric pain of three months' duration. For four years he had had intermittent claudication of the left calf, which appeared after 150 yards. For the past 18 months he had noticed increasing epigastric discomfort, which for three months had been severe and was associated with nausea, morning vomiting, and weight loss. Two months before admission he noted the appearance of a tender mass in the left mid-abdomen that had more recently increased in size.

On examination he was noted to be a thin ill-looking man who appeared older than his age. The blood pressure was 210/108. The veins in the neck were distended; the heart was enlarged and there was an apical systolic murmur. In the abdomen there was a visible swelling in the left upper portion which had an expansile pulsation, measured 5 by 12 cm., extended from the left of the umbilicus to just

FIG. 5.—Exterior of aorta and collagen-surrounded orlon removed from an animal three months after operation.

below the costal margin, and was compressible, tender, movable from side to side, but not superiorly and inferiorly. Peripheral pulses were decreased bilaterally and neither posterior tibial pulse was palpable.

Aortography showed a large aneurysm of the abdominal aorta extending from just below the kidneys down to and involving both common iliac arteries. It was evident that the aneurysm was expanding, that rupture was imminent, and that intervention was necessary. Operation was performed through a long midline incision. The aneurysm extending from 1 cm. below the kidneys to 2 cm. below the bifurcation was excised and an orlon prosthesis anastomosed end-to-end to the aorta above and to each common iliac artery below. After operation the femoral pulses were good. He experienced a fall in blood pressure during the first 30 minutes of the operation and afterwards passed little urine. His blood urea rose to 332 mg. per 100 ml. by the fourth day, and he became comatose and died. Necropsy revealed marked renal fibrosis and atheroma of the renal arteries. The orlon prosthesis was patent and the anastomosis intact. Death was due to failure of the diseased kidneys to function following the period of hypotension during operation.

Case 2

A 62-year-old male clerk of works was admitted to St. Bartholomew's Hospital complaining of pain in the leg on walking. Two years previously he had noticed that pain developed in the left calf after walking about 200 yards.

FIG. 6.—Orlon prosthesis in place on iliac vessels of Case 2 after completion of side-to-side anastomoses.

It had steadily increased in severity until the present, when it occurred after 75 yards of slow walking. He had been forced to stop work because of the pain. There was no rest pain or ulceration.

On examination the blood pressure was 200/100. Major abnormal findings were limited to the extremities, where the left foot was colder than the right, and paled quickly on elevation to 20 degrees. Pulses were completely absent on the left, but present though diminished on the right. Aortography revealed obstruction of the left external iliac artery.

The ischaemia was considered to be too severe for relief by ganglionectomy alone, and it was decided to use an arterial prosthesis. Operation was performed through a left paramedian incision. The left iliac vessels were exposed and a tube of orlon 5 in. (12.5 cm.) long was anastomosed to the left common iliac artery above the block and to the left common femoral artery below it (Fig. 6). The anastomoses were done side-to-side to make larger stomata. The existing collateral circulation was not disturbed. A left lumbar ganglionectomy was also performed. Post-operatively the pulses were all present in the left leg and stronger than in the right. Six months after operation he was able to walk three-quarters of a mile without claudication and the pulses remained present and strong.

Case 3

A 67-year-old company director was admitted to St. Bartholomew's Hospital complaining of a large pulsating swelling in the left groin. For many years he had noticed

a small lump in the left lower abdomen, which three weeks before admission had suddenly enlarged and started to pulsate and had become very prominent. There was a history of three myocardial infarctions at ages 64, 65, and 66, and moderate exertional dyspnoea and angina since the last infarction.

On examination the pulse was 88 and grossly irregular; the blood pressure was 180/105. The heart was not enlarged, but auricular fibrillation was present. In the abdomen there was a large pulsating visible mass in the left lower quadrant just below the umbilicus and extending down to the inguinal ligament. Its most prominent part was pushing out the anterior abdominal wall. The pulses were diminished bilaterally and absent distal to the popliteal artery on the left. Because of its possible harmful effect on renal function, aortography was not done. Operation was performed through a long left paramedian incision and a huge abdominal aneurysm was excised. It was 8 in. (20 cm.) in antero-posterior and 5 in. (12.5 cm.) in lateral extent. A λ -shaped orlon graft was placed from 2 in. (5 cm.) below the renal arteries to 3 in. (7.5 cm.) beyond the bifurcation and anastomosed end-to-end to the aorta above and to the common iliac below. Post-operatively he has had good pulses in both legs, and the prosthesis has functioned perfectly in the five months since operation.

Preparing the Prostheses

1. *The Seam.*—Ordinary fine white nylon sewing thread (No. 102) has been used to sew the seam, as orlon thread was not available to begin with. More recently pure orlon thread has been used. No difference has been discernible in the results from the two materials. A sewing machine is used to sew the seam and three rows of stitches are inserted close together and about 5 mm. from the free edges of the cloth. The ways in which the cloth is folded and sewn can be seen in Fig. 7. Prostheses for end-to-end or side-to-side anastomosis need only one longitudinal seam, for they are made from a single piece of cloth folded upon itself. The ends of the prosthesis intended for side-to-side use are closed by seams which lie close to the stomata. This avoids having a blind bag at each end (Fig. 7). Two pieces of cloth of the same shape are placed one on the other and sewn together when a branching prosthesis is needed. More seams are then required. A prosthesis for the aortic bifurcation is shown in Fig. 7. The same principle may be used for a greater number of branches.

2. *The Ends.*—Sutures placed close to the edge of a single thickness of cloth may pull out; therefore the ends are folded over. The folding is done before sewing the seams to avoid narrowing the ends of the tube.

3. *Size.*—Rough dimensions may be obtained from angiograms. The length is estimated without great difficulty. The diameter measured from the arteriogram tends to be smaller in obliterative disease and larger in aneurysmal disease than is needed in the operation. The diameter of the prosthesis as it lies flat and undistended needs to be

FIG. 7.—Diagrams to show folds and seams of prostheses for (from left to right) end-to-end, bifurcation, and side-to-side insertion.

approximately twice the diameter measured on the arteriogram film. It is convenient to have two or three prostheses of slightly different dimensions prepared before operation. One of them is usually found to be of the correct size. Should it prove too long it is easy to unpick some of the seam and trim it to the required length.

4. *Sterilization.*—The completed tubes are sterilized by boiling or autoclaving before operation. The latter is preferable. It is important to avoid folds or wrinkles in the cloth. The completed prostheses are smoothed with an electric iron before autoclaving. This is particularly helpful in keeping the folds at the stomata turned conveniently backwards so that suturing is facilitated when the time comes. Glass rods or small test-tubes are inserted inside the prostheses to prevent wrinkling during autoclaving.

Discussion

The advantages of these cloth prostheses over homografts are obvious. They are far more easily obtained and there is no anxiety about their sterility. They have, however, limitations. They cannot be used across the line of flexion of a joint, or certainly not if the joint is to be acutely flexed in the immediate post-operative period, for if this is done the tube is folded, the lumen obstructed, and thrombosis follows. This was the result when a prosthesis was inserted in a dog from the aorta to the femoral artery and the hip-joint flexed. Perhaps if flexion was avoided by splintage or other means until a firm collagenous wall had formed success might be obtained. Until this point is elucidated further we have avoided using a prosthesis below or across the inguinal ligament in patients, relying still upon homografts for this region.

A point of technical interest became evident when the aortograms were examined. When the classical Carrel everting suture was used a definite constriction was always produced at the anastomosis. This did not occur when a simple over-and-over running suture was used without eversion of the inner surfaces. The latter type of suture also has the advantage of greater speed and ease of execution.

The idea of using seamless tubes soon comes to mind when considering prostheses, and through the kindness of Messrs. Ethicon Sutures we have had some of these for preliminary trial. Certain disadvantages came to light which were not at first obvious. A turnover at the ends is desirable, and this necessarily produces some constriction, which is undesirable in the smaller-lumen tubes. Also, where branches are involved they are less adaptable for use compared with the prostheses made to measure. However, there is no doubt that with further trial still better prostheses will be evolved.

Summary

Experimental studies using "orlon" cloth prostheses to replace arteries of dogs are described.

The prostheses can be inserted end-to-end, end-to-side, or side-to-side into the arterial tree of the host. Branching prostheses may also be used.

Their clinical use in the treatment of arterial disease is reported.

Technical points in preparing the prostheses are outlined.

Advantages and disadvantages of prostheses compared with homografts are discussed.

We are grateful to many colleagues who have helped with this work. Professor Sir James Paterson Ross has given advice and encouragement, and Professor E. C. Amoroso has given us hospitality and facilities at the Royal Veterinary College for the animal studies. Dr. Hugh Cleland has helped with some of the operations. Miss D. Aitken has given skilled technical help, particularly in preparing the prostheses.

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SENSITIVITY TO FIVE ANTIBIOTICS OF A FURTHER 200 STRAINS OF STAPH. PYOGENES ISOLATED FROM OUT-PATIENTS

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Three years ago a report was made from this laboratory of the sensitivity to five antibiotics of strains of *Staphylococcus pyogenes* isolated from out-patients (Birnstingl, Shooter, and Hunt, 1952). It was found that, although the majority of staphylococci isolated from in-patients at that time were resistant to penicillin, resistant staphylococci were isolated from only 32 of 200 out-patient infections. No strains were resistant to streptomycin, chlortetracycline, oxytetracycline, or to chloramphenicol. In view of the continued prevalence of penicillin-resistant staphylococci in hospital wards, and the increasing number of strains found to be resistant to the later antibiotics, we have again examined 200 strains of *Staph. pyogenes* isolated from out-patient infections to see if resistant staphylococci are responsible for more of these infections than was the case three years ago.

Sources of Staphylococci

Swabs were taken from patients with acute infections of the skin and subcutaneous tissues attending the casualty department between October, 1954, and March, 1955. Whenever possible, swabs were taken on the first attendance, or, if this was not possible, when a lesion was opened. Swabs taken from patients attending other out-patient departments of this hospital, such as the skin and ear-nose-and-throat departments, were not included in the series, and care was also taken to exclude patients attending other hospitals, or who had recently been discharged from hospital wards.

Methods of Isolation and of Testing Sensitivity

All the swabs were sown direct on to two horse-blood-agar plates from which cups had been cut with a cork-borer. After inoculation these cups were filled with penicillin 10 units/ml., streptomycin 250 µg./ml., oxytetracycline 50 µg./ml., chloramphenicol 250 µg./ml., and erythromycin 100 µg./ml. respectively. Staphylococci which coagulated plasma in a tube were regarded as *Staph. pyogenes*: those which were inhibited by antibiotics to approximately the same degree as the Oxford H staphylococcus were described as sensitive.

Dilution sensitivity tests were carried out for all the antibiotics used with the exception of penicillin. For these tests stock solutions of streptomycin calcium chloride complex (1,000 µg./ml.), oxytetracycline (100 µg./ml.), chloramphenicol (1,000 µg./ml.), and erythromycin (100 µg./ml.) were prepared in distilled water and stored at -8° C. The solutions of streptomycin and chloramphenicol were replaced every two months; solutions of oxytetracycline and erythromycin were made up weekly. For testing, series of two-fold dilutions of each of the four antibiotics in nutrient agar plates were prepared immediately before use, each plate