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LATE RESULTS OF DIRECT SURGERY OF THE AORTIC BIFURCATION AND ITS MAJOR BRANCHES

BY

F. B. COCKETT, M.S., F.R.C.S. AND A. G. NORMAN, F.R.C.S.

Consultant Surgeon

Senior Surgical Registrar

St. Thomas's Hospital, London

[WITH SPECIAL PLATE]

The replacement of the terminal aorta and its main branches by stored homografts for obliterative disease or aneurysm is an operation which is being performed with increasing frequency. More recently (Hufnagel, 1955; Rob, 1956; Owen, 1956; Kinmonth *et al.*, 1955) these vessels have been successfully replaced by plastic artificial arteries made of "orlon," "nylon," or polyvinyl sponge, particularly in cases of aneurysm. After new and technically successful procedures such as these have been practised for a number of years it is well to review and take stock of the results carefully, for it is only as the long-term follow-up results begin to emerge that a true perspective can be obtained. Although large numbers of these operations have been reported from various centres (Linton, 1956; Rob *et al.*, 1956; DeBakey *et al.*, 1955), so far few detailed follow-up studies over an adequate period of time on individual series have appeared. In our experience any follow-up of less than one year is inadequate for assessing results in this type of surgery. It is during the first year that delayed occlusion of anastomosis is most likely to take place. It is only on such figures, combined with an estimate of the mortality and morbidity, that the indications for these procedures can be finally assessed.

Thus the purpose of this paper is threefold: (1) to describe our experience with 30 patients in whom reconstruction or replacement of the aortic bifurcation or one of its major branches has been carried out, and to describe the follow-up results to date; (2) to enumerate some of the lessons we have learned on the technique of doing these operations and handling the patients; and (3) to present some conclusions as to the long-term results which may be expected, and therefore on the indications for operative treatment. We have confined this paper to our experiences with the large arteries, ranging from the aorta to the common femoral. Our experiences with the commoner femoral-artery occlusions will be the subject of a further paper.

Clinical Material

Of the 30 patients, 26 came to operation because of an arteriosclerotic thrombosis of the aortic bifurcation or one or other common or external iliac artery; 4 patients had an aneurysm of the aorta.

The symptoms caused by the high arterial occlusions depend on the situation and degree of occlusion and the age of the patient and whether or not there is further arterial disease in the limb lower down. But, in general, there are three grades of severity of symptoms.

Grade I: Whole-leg and Buttock Claudication.—After a certain amount of exercise the patient complains of an aching pain which may start either in the buttocks or in the calf; but unless the exercise ceases it rapidly spreads to the thigh and the patient is pulled up by a severe ache and feeling of uselessness in his buttocks, thighs, and calf. The pain disappears after a minute or so standing still. This typical spread of exercise pain in buttocks, thigh, and leg is often described by the patient as rheumatism or lumbago, or just as a general ache and feeling of uselessness. Severe pain or cramp is seldom complained of, and so the symptoms are often misinterpreted. Several of our patients with whole-leg and buttock claudication have had months or years of physiotherapy for lumbago and rheumatism before the true nature of the pain was elucidated by finding that one or other femoral pulse was missing.

Grade II: Cold Leg.—With a local occlusion of the bifurcation or one or other common iliac artery, whole-leg and buttock claudication may be the only symptom. But if the thrombosis is a little more widespread, and the patient older so that the collateral circulation is not so good, then he may also complain of a persistent cold foot or feet and sometimes numbness in the foot; at this stage, too, some wasting of muscles may appear.

Grade III: Incipient Gangrene.—Finally, with a localized occlusion of a major branch of the aorta in addition to arterial disease lower down in the limb (such as local femoral or popliteal occlusion or thrombosis) the severe ischaemic symptoms and signs appear. These are rest pain, robbing the patient of his sleep at night, with numbness and coldness of the toes and foot. Rubor on dependency is seen, and impending gangrene of one or more toes may be present.

In all the cases of abdominal aneurysm the symptom necessitating operation was pain.

Methods

The surgical methods used for dealing with these thrombosed arterial segments or aneurysms have been of three kinds. (I) Replacement or by-passing the occluded segment with a stored arterial homograft. Our "artery bank" and method of storage are exactly the same as those introduced into this country in 1950 by Eastcott (Eastcott, 1953). This method of reconstruction was used in 18 cases. (II) Replacement by a plastic "artificial artery," either of polyvinyl sponge (three cases) or of orlon (three cases). (III) "Disobliteration" or "endarterectomy" of an occluded segment. This method, originally described by Dos Santos (1947) and Reboul and Laubry (1950), involves opening the artery and removing the thrombus from inside. Its ideal application is to a large artery, with a short localized occlusion with good normal artery on either side. This method was used in six cases.

We propose now to tabulate our results under these three headings.

Series I: Replacement or "By-passing" of the Occluded Segment with a Stored Arterial Homograft

Table I gives details of results and length of follow-up in this group of 18 patients, and the accompanying diagrams record the type of operative procedure in each case. In all cases a deep frozen homograft collected and preserved in our "artery bank" after the method described by Eastcott (1953) was used. In the earlier cases the grafts were collected with full sterile precautions and were not subjected to further sterilizing. Since late 1955, however, all our grafts have been sterilized by half an hour's immersion in ethylene dioxide (Hufnagel *et al.*, 1954). We have, however, found that in spite of this no relaxation of the sterile precautions when taking the graft can be allowed. Also, perhaps even more important, the donor must not have been dead more than eight to ten hours before the graft is taken; with grafts removed later than this one cannot be absolutely sure of sterility, as the process of post-mortem autolysis seems to be associated with a rapid spread of bacteria throughout the body, and they may be found within the vasa

vasorum of the graft and thus not reached by a surface sterilisant. This question of the absolute sterility of grafts is of the utmost importance—as the presence of staphylococci on a suture line will lead to late leakage and rupture. There are two cases in this series (Nos. 10 and 13) in which late leakage and rupture of an anastomosis was probably due to this factor. It is possible that sterilization of the grafts by x rays is the most satisfactory method (Meeker and Gross, 1951), and this is under investigation at present.

Indications for Operation

In nine of the patients the indication for treatment was severe claudication in one or both legs. In all cases the claudication was getting steadily worse and was causing the patient considerable anxiety, and in about half of them it was actively interfering with their work. In the other nine cases the ischaemic symptoms were more severe—ischæmic numbness and coldness and rest pain, with in three cases minor gangrene. These patients were all facing loss of a limb in the near future and therefore operation was undertaken to save the limb.

TABLE I.—*Series I: Replacement or By-passing with Stored Homograft*

Case No.	Sex and Age	Date of Operation	Procedure	Result	Follow-up	Remarks
1	M 50	10/2/53	Short-segment end-to-end graft of right common femoral, just at inguinal ligament level	Full return of pulses	4 yrs. 5 mths.	Graft functioning perfectly 4 yrs. 5 mths. after operation. Patient symptomless
2	M 57	19/2/53	Right common iliac to right external iliac, end-to-end anastomosis	Full return of pulses	4 yrs. 2 mths.	Aortic bifurcation above graft occluded 1 yr. after operation. Return of claudication to right leg, with some rest pain. (Has angina)
3	M 47	19/5/53	Left common iliac artery resection; end-to-end graft	Return of pulses	3 yrs. 1 mth.	Complete relief of claudication. Died of hypertension 3 yrs. 1 mth. after operation. At necropsy graft patent and indistinguishable from normal artery
4	M 60	15/2/54	Aortic bifurcation resected: end-to-side on right external iliac; end-to-end on left internal iliac	Full return of pulses	3 yrs. 2 mths.	Left end-to-end anastomosis occluded about 8 mths. after operation. Right end-to-side anastomosis still functioning. Has angina but is still at work
5	M 61	31/1/55	Aortic bifurcation resected: end-to-side to right femoral artery; end-to-side to left external iliac	Full return of pulses	2 yrs. 6 mths.	Perfect result maintained. All pulses present. Symptomless warm lower extremities
6	F 65	20/3/55	Right common iliac near bifurcation of aorta to right external iliac	Failure. Pulses did not return	2 yrs. 4 mths.	Lost right leg but otherwise well. Right leg pre-gangrenous and due for amputation unless graft could save it
7	M 46	17/5/55	Left common iliac (close to bifurcation) to left superficial femoral in leg (end-to-side)	Graft functioned well	2 yrs. 3 mths.	Severe rest pain with ischaemic ulcer of ankle. Graft relieved pain, healed ulcer, and averted amputation; is still patent
8	M 49	18/7/55	Bifurcation graft. Distal ends, end-to-side anastomosis on right side, end-to-end on left	Full return of pulses	2 yrs.	Complete relief of severe claudication. At full work
9	M 48	3/11/55	By-pass graft from right common iliac to common femoral	Graft functioned well	1 yr. 9 mths.	Graft averted major amputation; two toes only lost. Doing sedentary work
10	M 56	6/4/55	Aortic bifurcation graft. Distal limbs, end-to-side anastomoses	Full return of pulses	2 yrs. 3 mths.	Severe staphylococcal enteritis developed after operation. Later an infective false aneurysm appeared from leakage at right external iliac anastomosis. This had to be destroyed, and as a result patient lost right leg. Other limb of graft still functioning well
11	M 57	5/7/56	Aortic bifurcation graft. Distal limbs, end-to-side anastomoses	Full return of pulses to left leg; right leg cold and dead	1 yr.	Complete recovery of left leg (which was the bad one) maintained. Right leg amputated above knee because of a popliteal embolus sustained at operation
12	M 49	13/8/56	External iliac to common femoral (end-to-end)	Full return of pulses	1 yr.	Disabling claudication of left leg, causing loss of work. Now back at work with no claudication
13	M 43	26/11/55	Aortic bifurcation up to renal arteries. Distal limbs end-to-side	Full return of pulses	Died suddenly 1 wk. after discharge from hospital	Disabling claudication. Operative result perfect; discharged fit and symptom-free. Died suddenly 1 wk. after discharge after attack of acute abdominal pain. Probably ruptured aortic anastomosis due to sepsis, as <i>Staph. aureus</i> grown in broth culture of piece of graft inserted at operation
14	M 53	19/11/56	Aortic bifurcation: right limb end-to-side; left limb end-to-end	Full return of pulses below graft	9 mths.	Severely handicapped with threatened gangrene of right leg and severe claudication. 5 mths. after operation left end-to-end anastomosis occluded with return of claudication in left leg. Right leg maintains full improvement. Underwent sympathectomy and soleus denervation for left leg, with considerable improvement. Now back at sedentary type of job
15	M 48	5/12/56	Aortic bifurcation. Right limb end-to-side to right superficial femoral; left limb end-to-side left common femoral (both below inguinal ligament)	Full return of pulses	8 mths.	Disabling claudication. Had previously had a polyvinyl sponge graft inserted (elsewhere) which had thrombosed. At present operation thrombosed polyvinyl graft removed and homograft inserted. Now back at full work
16	M 53	9/1/57	By-pass graft from left common iliac to left common femoral	Full return of pulses	Died 2 wks. after operation	Disabling claudication of left leg. Operation technically very successful. However, chronic paralytic ileus followed by chest complication developed. Went steadily downhill and died 2 wks. after operation. At necropsy chronic paralytic ileus and infarction of lower lobes of both lungs found. Graft functioning perfectly. No satisfactory explanation of death
17	F 43	8/5/57	Aortic bifurcation. Right end-to-side. Left end-to-end (good fit)	Full return of pulses	4 mths.	Increasing claudication of whole lower limbs which was gradually disabling her. Full return of pulses and completely satisfactory result maintained during relatively short follow-up
18	F 57	1/7/57	Aortic bifurcation. Both ends, end-to-side to external iliacs	Full return of femoral pulses	2 mths.	Continuous rest pain in left leg, preventing sleep; also claudication at about 20 yd. and cold, numb feet. After operation immediate relief from rest pain and warm extremities

Mortality

In this group of 18 cases there were two deaths. The patient in Case 13, after a technically very successful operation, had an uninterrupted convalescence and was discharged symptom-free and afebrile three weeks after operation. One week later he was seized with acute abdominal pain and died suddenly that same afternoon. No necropsy was performed. In this case, although ordinary bacterial culture of a piece of the graft taken at the operation, by wiping it on an agar plate, was sterile, culture in broth gave a growth of *Staphylococcus aureus*. It is our belief that this case represents a late rupture of the anastomotic line due to sepsis in the graft.

The patient in Case 16 died with progressive paralytic ileus, massive infarction of both lower lobes of the lungs, and progressive renal failure. Again this was a technically successful and smooth operation, and the ultimate cause of death was never satisfactorily fathomed.

The rest of the patients (except Case 3) are alive and well, and most of them are working at the time of writing.

Morbidity and Complications

These are all fairly major operations on a group of patients with arteriosclerosis and in the 45-65 age group. The incidence of major complications has been very low. A certain amount of post-operative ileus is an inseparable accompaniment of an extensive retroperitoneal dissection, and continuous suction and an intravenous drip for two to four days have usually been necessary. Blood transfusion has been required in all cases.

In one case (Case 6) the graft was a failure owing to an unsatisfactory technical anastomosis at the aorta, where a large plaque interfered with it. In the light of later experience this could have been avoided by either resecting the whole bifurcation or simply doing a thrombendarterectomy of the occluded segment. However, this graft was not functioning at the end of the operation and the patient lost

her right leg. This operation was undertaken to avert an amputation, and its failure meant the loss of her "bad" leg only.

A major complication occurred in two cases. In Case 10 a fulminating staphylococcal enteritis developed the day after operation from which the patient nearly died. He survived this with massive saline infusions and antibiotic therapy. About six weeks after operation, however, it became apparent that he had a false aneurysm due to leakage at the site of the anastomosis of the right limb of the aortic bifurcation graft to the right external iliac artery. This anastomosis had to be destroyed completely at a subsequent operation, and as a result his right leg had to be amputated. However, he recovered from all this; his left anastomosis is still working and he is back in active life again with an artificial limb.

Case 11 represents the worst complication encountered. Here operation was undertaken to avert amputation of the left leg. Unfortunately, at operation an embolus from the site of the graft was allowed to slip unnoticed into the right popliteal artery, causing gangrene and necessitating loss of the right leg. The net result was that the patient's "bad" leg recovered completely and is in full use with all pulses present to-day, but he lost what was his "good" leg.

This complication of an embolus slipping down into the distal arteries after release of the clamps on the aorta must be guarded against. Now we never complete an arterial anastomosis before opening the proximal clamp and "flushing out" any clot which may be in the vessel proximal to the clamp.

Technique of Inserting Grafts

One of the most interesting lessons which has emerged during the follow-up of these patients has been the superiority of the end-to-side type of arterial anastomosis over the end-to-end type. In an end-to-end anastomosis between a graft (which should be in good condition) and a

Diagrammatic Representation of Operative Procedures in Series I (Table I) (Numbers refer to cases)

host artery (which is usually arteriosclerotic to some degree) a certain amount of irregularity and constriction is almost bound to occur. Moreover, there may be some disparity in size between host and graft. These factors, in our experience, lead to irregularity of flow over the site of the suture line and the gradual deposition of a platelet thrombus, which narrows and finally occludes the site of anastomosis. Thus late occlusion (after three to nine months) has been the main cause of failure of end-to-end anastomosis of arteries. The incidence of late occlusion is less in very large vessels such as the aorta or common iliac arteries. But in order to ensure that an end-to-end arterial anastomosis shall remain patent for many years the following conditions must be met: (1) the arteries to be anastomosed must be of exactly the same size—that is, they must be a perfect fit; (2) the suturing must be done with technical skill so that the suture line is not constricted in any way—this is difficult; (3) the “normal” graft artery must not be sutured to a thickened or irregular segment of host artery—this inevitably leads to irregularity of the suture line, obstruction of smooth flow, and, therefore, late thrombosis; and (4) the arteries must be sutured under the right tension, so that when the clamps are removed the anastomosis is not suddenly distorted.

Now, in handling arteriosclerotic arteries it is only rarely possible to fulfil all these requirements consistently, particularly Nos. 1 and 3. Therefore, early in 1954 one of us (F. B. C.) started to perform the smaller arterial anastomoses by an end-to-side technique (see Fig.). After a time it became apparent that this type of anastomosis was less prone

to late thrombosis than the end-to-end type. This, we believe, is mainly due to the fact that a much larger opening between the two arteries to be sutured can be obtained by this technique. The feasibility of using this type of anastomosis has already been shown by Kunlin using vein grafts (Kunlin, 1949, 1951).

In the present series comparison of the late results of end-to-end and end-to-side anastomoses is instructive. Cases 2 and 14 (see Table I) are of particular interest. In both of these the arteries were in very bad condition; both had an aortic bifurcation graft inserted with the right-hand limb sutured end-to-side into the right external iliac artery and the left-hand limb sutured end-to-end on to the left common iliac artery. In both cases the end-to-end anastomosis became occluded after eight months and five months respectively. In both cases the right end-to-side anastomosis remains patent after three years and ten months respectively.

All the end-to-end anastomoses in this series which have remained patent over two years or more have been between arteries of large size; the artery at the site of the anastomosis has not been diseased; and a “good fit” between graft and host artery has been achieved. There have been ten end-to-end anastomoses between major arteries followed up for one to three years, with two late occlusions; and nine end-to-side anastomoses (all on more diseased segments of artery and on artery of smaller size than the former group) followed up for one to three years with no incidence of late occlusion. In fact, in the whole of the series there has not yet been a case of delayed occlusion of an end-to-side type of anastomosis.

Our experience with grafting of the smaller arteries such as the superficial femoral artery has amply confirmed the superiority of the end-to-side type of anastomosis. The results of other workers, notably Linton (1955), Crawford and DeBakey (1955), and Martin and Gaylis (1957), have also confirmed this.

A further and very important advantage of this technique is that once the aortic anastomosis has been completed the two ends of the bifurcation graft can be taken down well beyond the diseased area without further dissection and disturbance of existing collateral vessels, and implanted into as healthy a portion of artery as can be found lower down. Fig. 1 (Special Plate) shows the pre- and post-operative aortograms of Case 5 (Table I), in which the right-hand limb has been brought below the inguinal ligament and sutured end to side to the right femoral artery. Long areas of severely diseased artery can be by-passed in this way.

General Assessment of Results in this Series

In this group of 18 patients two have died in the early post-operative period as a direct result of the operation. Of the remaining 16, there has been a serious complication resulting in loss of a limb in three cases. (In two of these amputation would have been necessary even if no operation had been undertaken.) The remaining 13 cases have been successful in varying degrees. In one patient (Case 4) symptoms returned after one year owing to a fresh occlusion of the aorta above the graft. This patient illustrated the need for being thoroughly radical when dealing with arteriosclerotic disease which is widespread—he should have had an aortic bifurcation graft. In two other cases there has been late occlusion of one of the end-to-end anastomoses, but in both there is still improvement due to the patency of the other anastomosis. The remaining ten patients have had very good results. Three patients in particular have been rescued from amputation by the operation. These good results have been maintained for between two and three years in six of these cases.

Considering the uniformly serious and progressive nature of the arteriosclerotic occlusive disease for which these operations were undertaken these results are very encouraging. Nearly all the patients had nothing to look forward to but steadily progressive disablement with eventual loss of

Technique of end-to-side large-lumen anastomosis. Photograph is of an end-to-side anastomosis between a graft and common iliac artery, removed from a patient who died from other causes ten days after implantation (Case 16, Table I). Note complete absence of thrombus round suture line.

one or both limbs. These ten good results may therefore be looked upon as a salvage from certain serious disability. Moreover, as the tricks of technique and judgment have been learned the risk and complication rate has steadily decreased. It is also noteworthy that nine of these patients were under 50 and facing serious curtailment of their earning capacity during the most responsible period of their lives. The oldest patient in the series was 65. Two of the patients had angina (Cases 2 and 4). One only had hypertension (Case 1).

Series II: Replacement with Plastic Prosthesis (Polyvinyl Sponge) or Orlon Cloth

From Table II it will be seen that four of these six patients had an aneurysm of the aorta. The indication for operation here is increasing pain, which usually foretells rupture in the near future. One case (Case 2) had a leakage

some time before operation. In another (Case 4) leakage was actually taking place when operation was done as an emergency. One of the technical problems of excising abdominal aneurysms is that the aortic ends which are left after excision of the aneurysm are very large; in this situation an orlon tube made to fit the large aorta is the best prosthesis in our experience (Special Plate, Fig. 2). Orlon tubes have the advantages that they are easy to make, easy to sew and handle, and are incorporated in the body tissues after implantation (Hufnagel, 1955; Kinmonth *et al.*, 1955).

One case of aneurysm and two cases of aortic thrombosis had a compressed polyvinyl sponge tube inserted (Owen, 1956). One of these latter showed late thrombosis (Case 6). Although in the other two cases of replacement by polyvinyl sponge the prostheses are still patent, we have now given up the use of this material for the following reasons: (1) it is treated more like a foreign body by the tissues—it is encapsulated and walled off, and fibrous tissue does not

TABLE II.—Series II: Replacement with Plastic Prosthesis (Polyvinyl Sponge) or Orlon Cloth

Case No.	Sex and Age	Date of Operation	Procedure	Result	Length of Follow-up	Remarks
1	M 81	1/10/56	Replacement of aorta between renal arteries and iliacs; orlon fabric tube	All pulses returned to lower limbs	7 days; then died from pulmonary embolus	Had an abdominal aneurysm which was enlarging and giving pain. Came through operation very well and was quite fit, but died suddenly on 7th day from massive pulmonary embolus
2	M 64	17/3/56	Replacement of aorta between renals and iliacs; polyvinyl sponge prosthesis	All pulses returned to lower limbs	1 yr. 4 mths. (graft patent)	Leak from large abdominal aneurysm about 2 mths. before operation; was getting pain. Operation prolonged and difficult; cerebral thrombosis developed in post-operative period. This gradually improved, however. Now back at light work, and apart from slight residual aphasia and weakness of right hand is in good shape
3	M 69	8/10/56	Replacement of aorta between renals and iliacs; orlon fabric tube	Complete return of all pulses	10 mths.	Quite small aneurysm of aorta, but caused continuous throbbing pain. This symptom lost after operation and at time of writing patient is well and fit
4	M 68	17/4/57	Replacement of aorta between renals and iliacs; orlon fabric tube	Complete return of pulses	4 mths.	Admitted as emergency with leaking abdominal aneurysm. Pain and large solid mass in left flank with some skin bruising. Operation undertaken as emergency. Smooth convalescence and left hospital 3 wks. later, still well
5	M 66	8/3/56	Polyvinyl sponge prosthesis from aorta to right femoral artery	Complete return of pulses	Graft closed 5 mths. later. Died 9 mths. after operation	Obliteration of aorta up to renal arteries. Lost left leg (above knee) and getting severe rest pain of remaining leg, which would have necessitated amputation. Graft completely relieved pain and restored leg to normal. 5 mths. after operation graft re-thrombosed, symptoms returned, and in spite of attempt to restore patency of graft lost right leg. 3 mths. later died of sudden secondary haemorrhage due to low-grade spreading sepsis along polyvinyl tube
6	M 64	2/5/56	Polyvinyl sponge replacement of aortic bifurcation only	Good function of graft	1 yr. 3 mths.	Very severe multiple arteriosclerotic thromboses in main artery of both lower limbs; facing amputation. Graft done to replace stricture of right common iliac near bifurcation, in hope of improving flow to right limb. Although temporary improvement occurred, rest pain recurred and right limb had to be amputated. Now, 1 yr. 3 mths. later, still has good left femoral pulse and good left leg—i.e., graft functioning well. Has angina

Diagrammatic Representation of Operative Procedures in Series II (Table II) (Numbers refer to cases. A=before and B=after operation)

invade it and grow into its interstices and incorporate it firmly into the tissues as it does with orlon; (2) it tends to break and fracture in time if it is not made thick enough; and (3) there is a high tendency to late thrombosis with this material. These disadvantages have also been found by other workers (Martin and Gaylis, 1957).

The two cases of aortic obliteration and thrombosis in which we used polyvinyl sponge prosthesis have been unsatisfactory, although in Case 6 the graft is still functioning after 15 months. As a result of the lessons learned with these cases and some experimental work of Kinmonth, Taylor, and Lee (1955) we have come to the conclusion that plastic material is unsatisfactory for replacement in cases of arteriosclerotic thrombosis. Where a short-segment replacement of a very large vessel such as the dilated aneurysmal aorta is required, then plastic material is satisfactory, and we have found that orlon tubes fulfil all the requirements here and have behaved well. The long-term results reported by other workers (Hufnagel, 1955; Kinmonth *et al.*, 1955) confirm that for aneurysms this material is perhaps better than any other, although from numerous other reports it would appear that where a fairly short segment of a large dilated vessel like the aneurysmal aorta has to be replaced then a number of synthetic substitutes will do equally well. "Nylon" and "dacron" have both been used for grafts with success.

Series III: "Disobliteration" or "Rebore" of an Occluded Arterial Segment by Direct Removal of the Occluding Thrombus

This type of operation involves direct incision of the occluded arterial segment and removal of the obstructing atheromatous plaque and the propagated thrombus. Recently we have been doing this operation through several small arteriotomy openings, using a special instrument to strip out the thrombus. We have come to call this operation "arterial rebore," for this is exactly what it is. When reboring large arteries such as in the series described here heparin solution (1,000 international units to 100 ml. of saline) is used to flush out the artery frequently during operation, but the patient is not given heparin systemically after the operation. Six patients have had this type of operation, and details are given in Table III. The indications for operation have been the same as in Series I—namely, severe claudication of the whole leg in four, and to avert amputation for a severely ischaemic limb in two.

There has been no mortality in this group and the operation has proved shorter and easier than grafting, and thus the patients have been very little upset. It is certainly a less arduous procedure than grafting, both for patient and surgeon. The follow-up has not been so long as in the first group. In one case the rebored segment has continued patent for over a year, and in three cases a good result has been maintained and the new pulse kept for over six months. In one case (Case 6) rethrombosis occurred after two months, but in this instance the operation was performed in an attempt to save a very precarious limb from amputation and was successful in this object. Recovery has been maintained in spite of thrombosis of the rebored segment, and the limb is at present in no danger.

General Assessment of Results in this Series

This type of operation in suitable cases has given perhaps the most encouraging results. The mortality has been nil, there have been no major complications, and the follow-up results to date have been satisfactory. With improvements in the technique of "rebore" we believe that the indications for this type of operation can be considerably extended.

General Discussion

Before an operation can be recommended with confidence for a given disease it is necessary first to inquire carefully into the natural history and prognosis of the untreated malady. One must be sure that any operation which may be recommended is definitely beneficial and not merely meddling. Moreover, in a disease which is not immediately lethal, to make an operation acceptable the risk must be low, the possible severe complications few, and its long-term results reasonable.

Arteriosclerosis is a general disease, and its most serious complication—namely, localized arterial thrombosis—may affect cerebral arteries, coronary arteries, or limb arteries indiscriminately. Arteriosclerotic changes occur not uncommonly in relatively young individuals, and appear increasingly common in the 40–60 age group.

Incidence of Coronary Disease and Cerebral Thrombosis

From our material it would appear that patients in the 40–60 age group with arteriosclerotic occlusion of a major artery are not particularly affected with coronary or cerebral thrombosis as well. There were 20 patients under 60 in this series. Of these, only one had coronary disease either

TABLE III.—Series III: "Endarterectomy" or "Rebore" of Occluded Segment of Artery

Case No.	Sex and Age	Date of Operation	Procedure	Result	Length of Follow-up	Remarks
1	M 47	18/6/56	Removal of obstructing thrombus from left common iliac artery	Full return of pulses	1 yr. 3 mths.	Suffered from "whole-leg" claudication of left leg at about 50 yds. Arteries very good; had small fibrosed occluding thrombus at origin of left common iliac which was easily removed. Perfect result has been maintained
2	M 71	25/4/57	Removal of obstructing thrombus involving common femoral artery	Return of femoral pulse (below area of operation)	5 mths.	Severe ischaemia of right leg with rest pain and cold feet; facing amputation. Result of operation dramatic: rest pain disappeared overnight, and now able to walk comfortably. Has since had a coronary thrombosis from which he has recovered
3	M 44	28/3/57	Removal of obstructing fibrous thrombus from left external iliac artery	Return of femoral pulse	6 mths.	In addition had a long femoral occlusion in same leg. Combination of two arterial obstructions caused severe claudication at 30 yds. Successful removal of higher block in external iliac artery brought much improvement, and now able to walk 200 yds. before claudicating and to do his job (as a waiter)
4	M 40	22/5/57	Removal of obstructing thrombus in right common iliac artery	Full return of pulses	4 mths.	Whole-leg claudication for 1½ yrs., getting worse. Has had complete relief of symptoms during period of follow-up
5	M 48	3/7/57	Removal of obstructing thrombus from right external iliac artery	Return of femoral pulse (below operation site)	3 mths.	Bilateral claudication, worse on right, due to bilateral thrombosis of both external iliac arteries; also segmental thrombosis of both femoral arteries. Right external iliac artery operated on to relieve worse leg, which was beginning to impede him in his work. To date a good result with palpable femoral pulse and relief of claudication has been maintained
6	M 57	29/7/57	Removal of obstructing thrombus from left external iliac artery	Return of femoral pulse	2 mths.	Left leg cold, painful, and near gangrene. Operation followed by rapid recovery of leg, but difficult because only peripheral channel open was profunda artery. Thrombus removed from whole external iliac and common femoral to promote flow into profunda. At 2 mths. great improvement of leg maintained, but no pulsation felt in femoral region

at the time of operation or during the follow-up period. All patients had a complete cardiac examination with an electrocardiogram before operation.

In the ten patients over 60 the incidence of coronary disease was higher. Two had angina at the time of operation (and are still alive and well with their angina three years and one year respectively after operation). One patient showed electrocardiographic evidence of coronary disease, and four months after operation had a coronary thrombosis, from which he has recovered. One patient had a cerebral thrombosis after successful resection of an aneurysm. Thus in the ten patients over 60 the incidence of associated coronary or cerebral occlusion was 40%.

It follows that operation on patients in the over-60 age group should be undertaken only where symptoms are more compelling—for example, severe pain in an aneurysm, or threatened loss of limb in a case of arteriosclerotic thrombosis. In spite of this, it is perhaps noteworthy also how low has been the operative mortality and morbidity in this group (one early death and one late death in ten cases)—suggesting that there is no need to withhold operation where an indication exists.

Natural History of Untreated Disease

When a thrombosis of a major artery occurs a collateral circulation carries the blood round the block back into the main artery beyond the block. If only one major artery is blocked the only symptom is limb claudication, which may be more or less severe depending on the patient's age and the site and length of the block. In patients under 60 the claudication often improves rapidly after the initial occlusion and stabilizes itself within about six months. It may remain static for several years and then slowly get worse as age increases. If, however, the patient is unfortunate enough to acquire a second localized block lower down in the same limb, then symptoms will be severe, and there may be rest pain, pallor, coldness, and threatened gangrene. This state of affairs, if untreated, usually leads to early loss of limb.

Effect of Restoring the Circulation Past the Higher of Two Arterial Blocks in the Same Limb

On purely mechanical principles it might be expected that if the higher or proximal block was eliminated and the high-pressure pulsatile flow down the main artery to the second block was restored, then there would be more pressure and driving force available to send the blood round the collaterals of the lower block. This should result in a decrease of the ischaemic symptoms in the periphery. Working on this premise, we performed our first by-pass of a femoral arterial block in the presence of a complete posterior tibial thrombosis in a man with gangrene of four toes in 1953. The result was astonishing, for the gangrenous tissue round the site where the toes had been amputated suddenly became alive: new healthy granulations appeared, the black sloughs were rapidly demarcated and thrown off, and the amputation healed in a matter of three weeks. This result has been maintained over three years and the patient is still walking about on this leg.

No fewer than 11 of the 30 operations recorded here were of this variety; that is to say, the patient had a severely ischaemic leg and was facing amputation. Aortography showed a major arterial block (in aorta or common iliac or external iliac), and in addition a further block of an artery or arteries lower down (such as the femoral or popliteal). Grafting or "rebores" of the upper of the two blocks was then undertaken to save the limb. This was successful in nine out of the 11 cases. Case 18 (Series I) is a typical example of this group, and the history and the result of operation are worth recounting in detail.

The patient, a woman of 57, perfectly healthy in every other respect, was limited to about 10 yards' (9.2 metres') walking by claudication in her right leg. She could not sleep for more than two hours or so at a stretch before she was woken up by the "rest pain" in her foot. Both her feet were always cold, and

her right foot felt permanently numb. The claudication had first appeared about five years previously, but symptoms had steadily progressed and she had been a semi-invalid for a year. Loss of sleep particularly had made her very depressed. She had been advised that nothing but amputation would relieve her. On clinical examination of her pulses it was apparent that she probably had a blocked right common iliac artery. Aortography confirmed this, and showed in addition marked narrowing of the left common iliac artery. There was a long block in both superficial femoral arteries.

At operation on July 1, 1957, the aortic bifurcation and constricted common iliac arteries were resected and replaced by a homograft (see diagram of Case 18—Table I). Although no foot pulses reappeared owing to the blocked femoral arteries, the result of the operation was dramatic. Her rest pain and the numbness of her right foot disappeared overnight. Her feet became warm. She became a very enthusiastic sleeper—making up, as she said, for a year of wakeful nights. She is now a cheerful, not very old woman preparing to lead her accustomed active life again.

These cases are among the most rewarding in this type of surgery—representing salvage of a limb or limbs from amputation and complete rehabilitation of the patient.

Long-term Results

Our longest follow-up result is in Case 1 of Series I (homografts). This man still has a patent homograft in the common femoral artery—with all pulses present and complete freedom from claudication—four years and five months after operation. Case 3 of Series I had a perfect result from a graft of the left common iliac artery for three years and one month. The patient then died from hypertensive heart failure (one of the only two cases of hypertension in the series). At necropsy the graft was patent and "indistinguishable from normal artery." These two cases demonstrate that, provided the proper technique is used, perfect long-term results appear possible with homografts.

In addition to the two cases cited above, there have been three others in Series I in which a perfect result has been maintained, with full return of all pulses, for over two years. A further three cases have maintained a good result with all pulses present for over one year.

In Series II (plastic replacements) two polyvinyl grafts have remained patent for over one year, and two orlon grafts for 11 months and five months respectively.

In Series III (endarterectomy or rebore) one case has remained patent after one year and four months, and two cases after six and seven months respectively.

Follow-up results of under one year are not of much significance in direct arterial surgery, as delayed occlusion may occur any time within the first year. Our experience is that if a graft remains patent for a year the likelihood of late occlusion within the next three or four years is small. The first year after the operation is the critical time.

Indications for the Different Types of Operation

One of the most important technical lessons learned over the last five years is the superiority of the end-to-side type of arterial anastomosis in the handling of arteriosclerotic arteries of moderate and smaller size. This has improved the long-term results considerably. Late occlusion—after a period of six months or so—was the bugbear of end-to-end anastomosis in arteriosclerotic arteries. This is far less common with the end-to-side large lumen type of anastomosis.

On the basis of our more recent experience we have a gradually increasing preference for the closed technique of "endarterectomy" or "rebores," where the thrombus is "reamed" or "stripped" out of the artery with a special instrument through two or three small arteriotomy incisions. Improvements in technique are making this type of operation increasingly applicable. Its best indication at present is in the case where a short length of artery is blocked with fairly good artery at either end. Fig. 3 (Special Plate) shows the ideal case for this procedure.

If, however, the arteriosclerotic process involves the whole of the bifurcation and the common iliac arteries (as it often

does) the best long-term result is obtained with a homograft replacement of the whole of the bifurcation (if necessary up as far as the renal arteries), the two long ends of the bifurcation being brought down as low as is necessary to find good artery and anastomosed end to side. (Special Plate Fig. 1 well illustrates this principle.) Case 2 of Series I is a good example of how failure to observe this principle led to a poor result. A blocked external iliac artery was successfully resected and replaced by a graft. The patient remained symptom-free for a year, then the aortic bifurcation above the graft occluded, causing a return of symptoms. The aortic bifurcation was known to be extensively diseased at the time of the original operation, and for a permanent result the patient should have had a full bifurcation graft.

Finally, in aortic aneurysms we prefer a graft of orlon cloth. A number of such grafts tailored to all sorts of different sizes are kept in the theatre ready to hand for the occasion.

General Indications for Operation

On the basis of these results we now feel confident in recommending operation to any patient in the under-60 age group who has a major arterial occlusion and wants relief from his or her symptoms. If the lesion is a localized occlusion with reasonably good artery on either side, direct removal of the occluding thrombus from the artery—"re-bore"—is a sound and safe operation. If the arterial disease is more widespread, a better long-term result will be obtained by radical resection of the whole aortic bifurcation and by-passing the diseased segments on each side with a stored homograft.

In the over-60 age group one's attitude is tempered by the increased likelihood of other arteriosclerotic lesions such as angina. However, even in these patients where a clear indication exists—such as pain and impending gangrene of a limb—the benefits of this type of surgery far outweigh the risks.

Aortic aneurysms tend to occur in the 60–80 age group, and here the indication is steadily increasing pain, which is the usual prelude to rupture.

Summary

A detailed follow-up study of 30 patients with either arteriosclerotic occlusion or aneurysm of the abdominal aorta and its major branches, who underwent direct arterial surgery during the last five years, is presented.

Three different types of direct arterial surgery have been used: (a) replacement with stored homograft; (b) replacement with plastic prosthesis; and (c) "endarterectomy" or "re-bore" of the occluded segment.

The hospital mortality has been 7%. The delayed mortality (due directly or indirectly to the operation) has been a further 7%.

The specific indications for the use of these three types of procedure are given, based on the follow-up results reported.

The importance of performing an end-to-side large lumen type of anastomosis when using homografts for replacing or by-passing arteriosclerotic material is stressed, and the beneficial effect of dealing with the upper of two arterial blocks in the same limb is described.

On the basis of the follow-up results reported, and an analysis of these cases, general principles for recommending this type of surgery are suggested.

We would like to thank our many colleagues who have referred these cases. Also we record our grateful thanks to the many registrars and house-surgeons who have helped with these sometimes arduous operations, and the nursing staff of St. Thomas's Hospital and the Royal Waterloo Hospital, to whose care the low mortality in this series is largely due. We wish to thank Miss J. Dewe, our medical artist, for the illustrations.

ADDENDUM

Since this article was written one more polyvinyl graft has obliterated (Series II, Case 6). The patient has had slight increase of his claudication and symptoms in his left leg, but is in no immediate danger of amputation. This further strengthens the conclusions already mentioned above that polyvinyl alcohol sponge material is unsuitable for arterial grafting.

One further rebore of a common iliac artery and two further bifurcation grafts have been carried out successfully.

BIBLIOGRAPHY

- Crawford, E. S., and DeBakey, M. E. (1955). *Surg. Gynec. Obstet.*, **101**, 529.
 DeBakey, M. E., Cooley, D. A., and Creech, O. (1955). In *International Symposium on Cardiovascular Surgery: Henry Ford Hospital*, ed. C. R. Lam, p. 468. Saunders, Philadelphia.
 Dos Santos, J. C. (1947). *Mém. Acad. Chir.*, **73**, 409.
 Eastcott, H. H. G. (1953). *Ann. roy. Coll. Surg. Engl.*, **13**, 177.
 Hufnagel, C. A. (1955). *Surgery*, **37**, 165.
 Harvey, W. P., Rabil, P. J., and McDermott, T. F. (1954). *Ibid.*, **35**, 673.
 Rabil, P. J., and Reed, L. (1953). *Surg. Forum*, **4**, 162.
 Kinmonth, J. B., Taylor, G. W., and Lee, R. H. (1955). *Brit. med. J.*, **1**, 1406.
 Kunlin, J. (1949). *Arch. Mal. Cœur*, **42**, 371.
 — (1951). *Rev. Chir. (Paris)*, **89**, 206.
 Linton, R. R. (1955). *Surgery*, **38**, 817.
 — (1956). Cited by Rob, C. G., Eastcott, H. H. G., and Owen, K. (1956).
 — and Menendez, C. V. (1955). *Ann. Surg.*, **142**, 568.
 Martin, P., and Gaylis, H. (1957). *Brit. med. J.*, **2**, 371.
 Meeker, I. A., and Gross, R. E. (1951). *Surgery*, **30**, 19.
 Owen, K. (1956). *Proc. roy. Soc. Med.*, **49**, 340.
 Reboul, H., and Laubry, P. (1950). *Ibid.*, **43**, 547.
 Rob, C. G., Eastcott, H. H. G., and Owen, K. (1956). *Brit. J. Surg.*, **43**, 449.

GRAFT STERILIZATION

A BACTERIOLOGICAL AND HISTOLOGICAL STUDY OF THE RELATIVE MERITS OF ETHYLENE OXIDE AND β -PROPIOLACTONE AS TISSUE STERILIZING AGENTS, WITH SPECIAL REFERENCE TO ARTERIAL GRAFTS

BY

T. W. SUTHERLAND, M.D.

Senior Lecturer in Pathology

G. M. WILLIAMSON, M.D.

Lecturer in Bacteriology

K. ZINNEMANN, M.D., M.Sc.

Senior Lecturer in Bacteriology

AND

H. S. SHUCKSMITH, T.D., B.Sc., M.B., F.R.C.S.

Senior Clinical Lecturer in Surgery

From the Departments of Pathology, Bacteriology, and Surgery, School of Medicine, Leeds

[WITH SPECIAL PLATE]

In discussing a method for the preparation of freeze-dried arterial grafts Flewett *et al.* (1955) drew attention to the obvious advantages of using a sterilizing agent, which, they suggested, would render asepsis unnecessary during collection and would allow the use of post-mortem material for grafts. Previous workers have used either ethylene oxide (Hufnagel *et al.*, 1953) or β -propiolactone (LoGrippe *et al.*, 1955; Rains *et al.*, 1956; Berkin *et al.*, 1957).

Two questions arise if chemical sterilizing agents are used: (1) Can such agents effectively sterilize necropsy material intended for use as grafts? (2) Do such agents give rise to gross histological changes in the arterial wall? In this paper we compare ethylene oxide and β -propiolactone for sterilizing power and for failure to produce gross histological changes in graft material.

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FIG. 1A

FIG. 1B

FIG. 1.—Case 5, Series I. A: Pre-operative aortogram, showing widespread obliterative disease of aortic bifurcation and left common iliac artery with complete occlusion of right common iliac. B: Aortogram taken six months after operation, showing complete replacement by large homograft. The sites of the two peripheral end-to-side anastomoses are shown by arrows.

FIG. 3A

FIG. 3B

FIG. 3.—Case 4, Series III. A: Aortogram showing long narrowed segment of right common iliac artery. B: Operative photograph showing obstructing thrombus, which was removed from artery through two small arteriotomy incisions. (Thrombus is white object at bottom centre.)

FIG. 2.—Aneurysm of abdominal aorta: (A) before and (B) after replacement by an "orlon" tube. Note method of reinforcement of anastomosis by two polyvinyl cuffs.

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FIG. 1

FIG. 1.—Intimal lipid (black in figure) in prepared graft from donor aged 17. Lipid infiltration is here associated with formation of oval spaces. (Frozen section, stained scarlet-red. ×75.)

FIG. 2

FIG. 2.—Intimal lipid (black in figure) in prepared graft from donor aged 23. Note crenellated intimal surface. (Frozen section, stained scarlet-red. ×20.)