Aneurysms

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ONE OF the outstanding achievements of surgery over the last two decades has been the successful development of techniques for treating aneurysms. Aneurysm, in its various forms, has long been recognized (Edwin Smith papyrus, *circa* 1600 B.C. (Breasted, 1930); Aetius of Amida, 6th century A.D.) as a threat to life or limb, but until recently little could be done to avert impending disaster. As so often this surgical advance has also brought an increased understanding of the condition being treated. This review will concentrate upon our knowledge and our ability to treat aneurysms as it stands today, but tribute must be paid to the contributions of Hunter (Home, 1786); Cooper (1818, 1836), Matas (1888, 1902), and many others who over the centuries have set the scene for the day when surgeons would have practical methods for replacing diseased arteries (Carrel, 1908; Voorhees, Jaretzki & Bakemore, 1952). Methods of ligation or induced thrombosis either brought disaster or at most a very limited success. The weakened degenerative walls of aneurysms, by their very nature, do not allow the successful repair by use of their own substance, and in spite of many attempts failure was the inevitable outcome (Fig. 1). It was only with the advent of cadaver homografts that it became possible to replace major arteries, and by 1953 an ever-increasing number of reports of successful replacement of aneurysms by homografts were appearing in the surgical literature (De Bakey & Cooley, 1953). Homografts had their short-comings and limitations, however, and were soon superseded by arterial prostheses made from knitted or woven plastic yarn. This method holds pride of place today and it is now possible to replace the aneurysm by an arterial prosthesis of Terylene (Dacron) which will easily outlast the patient. The value of this surgery is indisputable (Szilagyi *et al.*, 1966; De Bakey *et al.*, 1964) and it is perhaps a suitable stage, after nearly 20 years' experience with the techniques, to stand aside for a moment to consider the hard-won lessons that have brought this spectacular advance almost into the category of routine surgery. This review is not by any means comprehensive but merely an attempt to highlight the fundamental principles that

FIG. 1. Surgical endeavour 30 years ago! An attempt was made to strengthen this aneurysm with kangaroo tendon (Professor Pybus, Newcastle-upon-Tyne).

have been established in this field. The more specialized procedures requiring such apparatus as the cardio-pulmonary by-pass machine will not be considered, but only those requiring minimal equipment. Aneurysm arising from degenerative states of the abdominal aorta and the peripheral arteries will be the main topic but something will also be said about traumatic aneurysms.

Pathology

The most commonly encountered aneurysm is that due to a senile degenerative state in the arterial wall. This is not the same condition as atherosclerosis, although both have features in common. Both conditions tend to be widespread although some areas

may be far in advance of the rest. Both may lead to deposition of thrombus and occlusion of vessels as might be expected of any disease state in the arterial walls. However, a glance is sufficient to show that one condition leads to a general widening of the arteries, often massive, and the other to a progressive loss of lumen without any increase in the overall diameter of the vessel; moreover the microscope soon confirms the degenerative state of the wall in aneurysmal disease (Fig. 2). The nature of this change is ill understood but it is seldom syphilitic in origin nowadays; perhaps until more is known the commonest variety should be regarded as a degenerative condition of uncertain origin, chiefly affecting the elderly.

The tendency to generalized widening of the arteries is of course a great help to the surgeon and an important factor in the high rate of success in this form of surgery. Fortunately in most cases the aneurysm itself is far in advance of the disease elsewhere so that the remaining arterial tree may continue to function well for many years. A local attack upon an expression of a generalized tendency is not therefore illogical, especially when thought is given to the precarious structure of a typical aneurysm and the complications that may arise from it. The typical aneurysm is composed of an outer layer of degenerative and greatly stretched original arterial wall, an intermediate layer of debris of varying texture and thickness, and an inner lining of compressed thrombus and clot, again variable in extent. This process may involve only part of the circumference, or the whole circumference over some distance and various descriptive terms, such as saccular or fusiform, are used to indicate this. The vessel wall may have given way to such an extent that the outer wall may no longer be discernible and a neighbouring structure, such as a vertebral body, forms a barrier retaining the contents of the

FIG. 2b

FIG. 2c

FIG. 2. Comparison of the microscopic appearances of normal aorta (a, $\times 30$) and of a typical abdominal aortic aneurysm (b, $\times 3$) which shows complete loss of the normal orderly structure. Its interior is filled with thrombosis and debris amongst which innumerable cholesterol clefts are evident (c, $\times 240$) (stained Orcein).

aneurysm. The intermediate layer commonly contains a large quantity of liquid fatty debris which is highly thrombogenic. Incautious handling of an aneurysm at operation may cause a disastrous discharge into the circulation of this material and consequent thrombosis of the peripheral arteries (Fig. 3).

Aneurysms are usually densely adherent to their surroundings and a neighbouring vein may be virtually inseparable, a fact of considerable surgical importance.

FIG. 3. Fatty debris (stained Oil Red O, $\times 240$) in clot removed from the arteries of a patient sustaining massive thrombosis during operation upon an abdominal aortic aneurysm.

An aneurysm commonly gives rise to the following dangerous complications: it may leak or frankly rupture with catastrophic consequences; it may discharge debris to occlude the distal circulation or it may undergo thrombosis carrying the process extensively to neighbouring arteries and causing severe ischaemia in the limbs. Any of these processes may occur at any time without warning and, for example, an abdominal aortic aneurysm that has been painless may nevertheless rupture abruptly.

The study by Estes (1950) gives clear indication of the dangers and, for instance, he found that an untreated abdominal aneurysm causes death in approximately one-third of the patients within 1 year of diagnosis. There is no easy way of deciding how unstable an aneurysm may be and it is always desirable that this unknown risk should be removed provided careful clinical evaluation shows, as it often does, that the patient's life expectancy is otherwise reasonably good and that the risks of surgery are not too great.

Diagnosis of aneurysm

The clinical features of aneurysm need little elaboration here. The presentation varies from accidental discovery of a swelling by the patient or his doctor, pain of obscure origin, through to violent pain and shock. The diagnostician must not, however, assume that a mass which pulsates is an aneurysm and careful examination for true expansile pulsation is necessary; certainly a mass of gland overlying the aorta can prove deceptive to casual examination. A plain X-ray often shows a rim of calcium in the wall of the aneurysm (Fig. 4). In the case of abdominal aortic aneurysm, aortography is usually best avoided since transfixing an aneurysm with a needle or passing an arterial catheter through

FIG. 4. A.P. and lateral X-ray views of the abdomen in a patient with abdominal aortic aneurysm. Here the aneurysm is clearly outlined with calcium but this is not always so.

it may prove dangerous; moreover the medium only demonstrates the remaining lumen and gives little idea of the detailed structure of the aneurysm so that the disease state may be grossly underestimated. It is best, therefore, to rely upon careful clinical examination, plain X-ray, and direct palpation at operation to give guidance in the technical decisions that are necessary. A good lateral view of the chest is essential to demonstrate the thoracic aorta since a massive overall expansion of this may give clear warning that the entire aorta is in an aneurysmal state and best left undisturbed. Needless to say the patient must have a thorough general examination by chest X-ray, ECG, blood chemistry, and if need be by an IVP.

With the limb arteries an arteriogram performed from above the aneurysm is usually desirable and gives valuable information upon the extent of the aneurysm, and the state of the arteries beyond the aneurysm, and hence the feasibility and nature of the operation to be performed.

Technique

Nowadays there are only two permissible basic surgical techniques for treating an aneurysm in a major artery: by direct substitution of an arterial prosthesis for the diseased portion of artery, or by the isolation of the aneurysm between ligatures and the restoration of the circulation past the aneurysm with a by-pass using either a plastic prosthesis or a vein graft. It is not necessary to resect the actual aneurysm and indeed attempts at a formal resection may not only cause the operation to be unnecessarily extensive but also expose the neighbouring great vein to danger. There is no more unpleasant complication than a laceration of, say, the inferior vena cava which is often difficult to control and may prove very dangerous. This complication occurs with great readiness if attempts are made to obtain a 'good surgical specimen', and vascular surgeons at an early stage developed the method of preserving the outermost layer of the aneurysm as a barrier between their activities and the neighbouring veins. The main bulk of the aneurysm is clot and debris which is scooped out, and back-bleeding from side branches controlled by sutures into the interior aspect of the remaining shell. The aorta and main arteries are only dissected in their full circumference above and below the aneurysm where they are comparatively healthy and not adherent; this is done so that controlling clamps may be applied and also to free the vessels sufficiently for anastomosis with the prosthesis. The outer layer of the aneurysm has an excellent blood supply and forms an ideal protective sheath to wrap around the prosthesis thus minimizing the chance of such later complications as fistulous communication and haemorrhage into neighbouring bowel. This

principle of preserving the outer layer of the aneurysm is of fundamental importance to the safety of the operation in all but the simplest of aneurysms. It is illustrated as applied to the abdominal aortic aneurysm in Fig. 5.

The safe use of the arterial prosthesis requires special comment. It is necessary that the prosthesis should be permeable since its ultimate incorporation with the tissues of the body and the satisfactory formation of an intimal lining to the 'graft' depends upon the ability of fibroblasts and a capillary network to grow through the fabric of the prosthesis. The form most commonly employed in replacing the abdominal aorta is a bifurcated tube of knitted Terylene (Dacron) (Crawford, De Bakey & Cooley, 1959). Heavy leakage of blood through the interstices of the material will occur unless these are sealed by allowing blood to clot throughout the meshwork of the fabric. This process is easily accomplished by completing the upper anastomosis, clamping off the lower end of the prosthesis, and then momentarily unclamping the aorta to allow blood to distend the prosthesis. The blood is allowed to clot within the prosthesis, this clot is then removed and the process repeated once or twice more until the fabric (and incidentally the upper anastomosis) is entirely 'waterproof' (Fig. 5b). This manoeuvre is of high importance since otherwise dangerously fast bleeding will occur through the fabric of the prosthesis. There is no difficulty in meeting this potential danger by the means described but understanding this requirement is fundamental to the use of an arterial prosthesis. Tightly woven fabrics that allow little initial leakage of blood are available and favoured by some surgeons. This type of fabric tends to fray as it is sutured and theoretically does not allow such free ingrowth of tissue as the more open knitted meshwork.

The ligature and by-pass technique is of value in aneurysms of the limb arteries and offers a safe but simple technique of especial value in the elderly. The artery is exposed at a convenient point above and below the aneurysm and a reversed saphenous vein graft or a Dacron tube anastomosed, end-to-side, at these points so as to act as a by-pass (Fig. 6a). The aneurysm may be isolated between ligatures so that it thromboses harmlessly or it may be 'obliterated' by opening it, evacuating the contents, and suturing any side branches which bleed back (obliterative endo-aneurysmorrhaphy) (Fig. 6b). If the aneurysm is ligated and left to thrombose its mass reduces steadily to insignificant proportions over the coming months, a process no doubt dependent upon the rich blood supply in the outer shell of the aneurysm. Although there are variations in this technique and a non-adherent aneurysm may be frankly resected and an autogenous vein graft or a

FIG. 5. Stages in the operation upon abdominal aortic aneurysm. (a) Preparing the aneurysm for insertion of prosthesis. All the loose debris will be scooped out and the aorta divided and trimmed just above the aneurysm. (b) 'Water-proofing' the prosthesis by distending it with blood. (c) The completed operation with the shell of the aneurysm wrapped round the prosthesis as a protective sheath.

FIG. 6. (a) The by-pass technique for dealing with femoral or popliteal aneurysm. (b) It may be preferable to open the aneurysm, remove all the loose debris, and suture off any vessels that bleed back.

prosthesis substituted, the techniques described have over recent years given a high yield of success

with minimal risk to the patient. Ligation of an aneurysm without restoration of the main arterial pathway is no longer justifiable since the insertion of a by-pass graft is a small addition which offers incomparably less risk of gangrene to the extremity and restores its full function. Attempts to induce thrombosis, for example by passage of a wire (e.g. Colt's operation), similarly offer unreasonable hazards with such doubtful benefit that they have been dropped from the surgical repertoire.

The leaking abdominal aortic aneurysm

This is by no means an uncommon problem and may well occur without any warning symptoms. Abdominal pain in the presence of a pulsating abdominal mass is very likely to be due to leakage from an aneurysm and if there is also evidence of haemorrhagic shock then the diagnosis is virtually certain. Approximately half of those patients reaching hospital alive can be saved if appropriate action is taken. The situation is highly unstable and may

deteriorate catastrophically at any moment; the rent in the aneurysm may well be temporarily plugged with clot, in its turn retained by nothing more than, say, peritoneum. If the patient shows clinical evidence of internal blood loss then no time should be lost in moving him to the threshold of the operating theatre. There should not be any real attempt at resuscitation since this is a situation which will not improve with time and transfusion of blood will in all probability cause a renewed bout of bleeding. During induction of anaesthesia no more blood should be given than is necessary to maintain life and the surgeon loses no time in making a full-length abdominal incision. The aneurysm is left strictly alone and the surgeon's first move should be to locate the abdominal aorta just beneath the diaphragm. This is surprisingly easy to do by touch alone if need be. The peritoneum over the oesophagus

phagus is first divided and the oesophagus displaced so that a finger may be worked round the aorta. A curved clamp, such as Crawford's, is then passed under the aorta and used to draw back a strong tape as a sling around the aorta (Fig. 7a). This provides an invaluable safety factor so that if the aneurysm 'explodes' the means for occluding the abdominal aorta at high level is immediately at hand. Occlusion of the aorta at this level will also shut off arterial supply to the kidneys and most of the viscera but local control of the aneurysm can almost certainly be effected within 15 min, a time that is usually well within the tolerance to ischaemia of these structures.

Having placed the means for emergency control around the aorta the surgeon should next locate the common iliac arteries and place slings around them since they can cause heavy back-bleeding. Blood transfusion may now proceed freely, monitored

FIG. 7. Some technical points in dealing with leaking abdominal aneurysm. (a) As a first step control is established on the infra-diaphragmatic aorta and the iliac arteries. A clamp is shown closed on the aorta as it would be in case of necessity. (b) The aneurysm has been opened and the aorta plugged with a finger or thumb. This allows restoration of blood flow to kidneys and the viscera whilst work continues to gain control on the infra-renal portion of aorta.

by a central venous pressure manometer. The surgeon at this stage proceeds with the operation along the usual lines, seeking at an early stage to place a clamp across the aorta above the aneurysm but below the renal arteries; this is nearly always possible since it is rare for there not to be at least $\frac{1}{4}$ in. of aorta below the renal arteries relatively unaffected by the aneurysm. Once the infra-renal aorta and iliac arteries have been clamped the aorta may be boldly incised and all the clot and debris scooped out; back-bleeding from the lumbar arteries is controlled by sutures. The aorta and iliac arteries are then divided and the prosthesis sutured into place to lie in the bed formed by the outer layer of the aneurysm.

But what if the aneurysm should burst as the surgeon is dissecting the main vessels leading to it? The emergency slings are immediately pulled taut and replaced by clamps: the aneurysm is split vertically over its full length and clot and debris rapidly scooped away until the aperture of the aorta leading into the aneurysm is seen or felt from within. A finger is placed into this and the infra-renal aorta thus localized freed so that a clamp may be put across it. If this takes more time than, say 15 min the surgeon should not hesitate to use his finger or thumb to plug the aorta and release the upper aortic clamp, thus restoring flow to the kidneys and viscera (Fig. 7b). This can be a life-saving manoeuvre, but in doing it care must be taken not to damage the all-important infra-renal aorta which is usually atheromatous and brittle; pushing debris from the aneurysm up and into the renal arteries is another danger to be avoided.

The leaking abdominal aneurysm may well tax the resources of a surgeon but is truly an occasion when the art of surgery transcends the science.

Femoral and popliteal aneurysms

These aneurysms are commonly bilateral. They are usually progressive and ultimately will either give rise to massive embolic occlusion of the distal arteries or occlusion due to their own total thrombosis; occasionally they may rupture. Thrombosis of the aneurysm usually puts the limb in jeopardy and is a very cogent argument for treating the aneurysm before this complication occurs. However, in some cases the arteries of the entire lower limb are found to be aneurysmal so that, for instance, the whole length of the superficial femoral and popliteal arteries may be tortuous and some 2 in. in diameter. In these diffuse aneurysmal states local treatment may have little point and conservative treatment may be wisest.

A Dacron prosthesis is suitable for the restoration of the common femoral artery but our preference is to use a reversed long saphenous vein for the

popliteal aneurysm. The graft is used as a by-pass or directly substituted for the aneurysm, according to local circumstances. The results, both immediate and late, are usually rewarding.

Carotid artery aneurysms

Usually the carotid aneurysm seen pulsating on the neck is in fact a tortuous expanded carotid or innominate artery rather than a true aneurysm. The patients are always hypertensive and if their hypertension is treated the vessel seldom causes trouble. Unlike aneurysms in the lower limbs, the attitude to the carotid aneurysm in the hypertensive patient should be conservative.

Results with abdominal aortic aneurysm and discussion on safety in surgery

The most commonly encountered aneurysm, and potentially the most lethal, is in the abdominal aorta. Many series have been published involving large numbers of patients and those by De Bakey *et al.* (1964), Szilagyi *et al.* (1966), and Graham *et al.* (1968) show what can be attained. Our own series from Oxford, although modest in numbers, does illustrate fairly typical results and the difficulties that may be encountered.

In a 10-year period eighty-three abdominal aortic aneurysms have been treated surgically; of these twenty-two were emergency operations for leaking aneurysms and these will be considered separately. There were three deaths amongst the sixty-one elective operations. One death was from pulmonary embolus a few days after the operation. The other two deaths were directly related to the pathological state of the aorta and were as follows:

(a) Whilst under dissection it was noticed that the aneurysm had ceased to pulsate and had in fact thrombosed. It subsequently became clear that the walls of the aneurysm were full of liquid fatty debris which had escaped into the circulation in large quantities. This had given rise to thrombosis in the aneurysm and the entire arterial system to the lower limbs which were totally ischaemic and showed a blotchy skin rash extending on to the buttocks. No way could be found to re-open the circulation and the patient died about 18 hr later. Microscopy upon clot removed from the arteries of the lower limbs showed masses of fatty debris mingled with clot wherever this was examined (Fig. 3).

This occurred early in the series. Now, a far less extensive dissection of the aneurysm would be attempted with presumably a diminished likelihood of rupturing fluid debris into the circulation. It does, however, illustrate on a massive scale the effect of discharge of fatty debris into the circulation (a process which is happening in small but repeated amounts from any atheromatous aorta). Large

pockets of fluid debris are commonplace in aortic aneurysms which should therefore be handled with reasonable gentleness and puncture with large needles, such as for an aortogram, avoided.

(b) The other death in this series occurred abruptly about 3 hr after a comparatively uneventful operation. Post-mortem showed that a massive haemorrhage had occurred from a split in the posterior aorta about $\frac{3}{8}$ in. above the upper anastomosis. It had been noted during operation that the aorta at this level was very diseased and brittle; moreover, it was above average size and it was necessary to 'pucker' it slightly to match its diameter to that of the prosthesis. We believe that the marked discrepancy in size between prosthesis and aorta had led to an uneven distribution in the strain upon the aorta so that it split subsequently; no doubt the fact that a clamp had been applied at about the same level also played a part.

When the surgeon encounters a brittle vessel with obvious discrepancy in size, or in fact if he has any serious doubts about the integrity of his anastomosis, the use of a cuff cut from the prosthesis as shown in Fig. 8 is a valuable way of supporting a doubtful portion of aorta. It must be emphasized, however, that this is no substitute for the careful placing of the stitches of the anastomosis which must include the outermost layer of the aorta since this is the only layer with any appreciable strength. It is all too easy for this outer layer to be missed because it has retracted away from the rigid and more conspicuous inner layer. This will certainly lead to disaster which a cuff cannot prevent and great care must be taken to ensure the proper placing of the sutures.

Amongst the other fifty-eight elective cases there were the usual crop of surmountable difficulties both at operation and postoperatively. Certainly several patients developed severe ECG changes and two required a peripheral arterial embolectomy, successful, postoperatively. There were no cases of renal suppression and mannitol was used in only two cases because the renal arteries had been temporarily occluded. Paralytic ileus was not a problem postoperatively, and we attribute this to:

(a) Delivery of the small bowel into a bag lined with thin nylon film. The bowel emerges from this in perfect condition. If the bowel has been wrapped in a moist towel it emerges in a tacky hyperaemic state and over the next few hours will pour fibrin onto its surface so that in effect multiple fibrinous adhesions develop. This may be a very important cause for so-called postoperative ileus and it seems essential to store the bowel in entirely congenial surroundings and not in a saline-soaked towel.

(b) At the termination of operation the bowel is stowed back loop by loop with the utmost care to

FIG. 8. Use of a cuff, fashioned from an unwanted portion of the prosthesis, to strengthen the infra-renal aorta and anastomosis.

place it in an ideal lie, without any tendency for a mass of small bowel, semi-twisted upon its mesentery, to overly and trap other loops from a different level.

(c) The omentum is carefully smoothed out to cover the entire small bowel and to be interposed between it and the abdominal incision.

(d) Finally the wound is sutured with the greatest care since a hidden wound dehiscence is yet another cause for 'postoperative ileus'.

Many of our patients have been followed over 6 years and although some have fallen by the wayside from coronary artery disease we have not encountered late deaths from failure of the aortic prosthesis or its anastomosis. Three of our patients have passed the 10-year mark and are still doing well.

There were eleven deaths amongst the twenty-two leaking aneurysms. In five of these the patients either died on the operating table or soon after leaving it. These were not all due to failure to control the haemorrhage before the heart failed. In three patients, who had suffered profound hypotension and massive blood loss, operation had been completed in a technically satisfactory manner but the circulatory state continued to deteriorate in spite of all efforts. The circumstances, especially in patients with pre-existing myocardial damage, are clearly capable of causing irrecoverable circulatory failure and it is as well to consider some of the reversible

factors which, if properly corrected, may save the patient who would otherwise succumb.

The most vital matter is of course early control of the haemorrhage itself, and we have certainly had at least two patients who were virtually 'dead' when a clamp was placed across the abdominal aorta just beneath the diaphragm; the effect of giving the heart a 'closed' circulation to work against was dramatic and both patients had their operations successfully concluded and are alive today.

The next most obvious need, after control of the haemorrhage itself, is the controlled restoration of blood volume. In this respect central venous pressure measurement is invaluable and transfusion should continue until this is restored and maintained at a normal value; it may be necessary to give a litre or more of blood guided by this means in the 24 hr after operation. A central venous pressure measurement catheter should therefore be inserted at the earliest moment. Other measures that may benefit the patient are the use of sodium lactate to combat metabolic acidosis from prolonged ischaemia, the estimation of blood gases to give warning of carbon dioxide retention or hypoxia, and the use of a respiratory ventilator or even a tracheostomy post-operatively. If the patient has suffered a prolonged or profound hypotension, or if there is any question of the renal arteries having been clamped, then mannitol is given. If it is clear that the patient is likely to remain in a critical condition after operation we insert a bladder catheter and certainly do this if mannitol has been used; a nasogastric tube is usually advisable and in order to minimize post-operative distension from swallowed gas it is given continuous low pressure suction, with hourly checks by a syringe.

Any or all of the measures outlined above may be desirable in a patient undergoing an elective operation for abdominal aortic aneurysm if undue difficulties are encountered during the operation.

Of the other deaths amongst the cases of leaking aneurysm two were from renal failure, one from pulmonary embolus, one from severe lung complications (early in the series and might have been saved by tracheostomy), and in two cases death was from renewed haemorrhage due to splitting of the aorta just above the anastomosis. Use of a cuff might have prevented this.

Regarding renal failure, we do not believe that operation for abdominal aortic aneurysm *per se* has any unique tendency to cause this. Usually there is no difficulty in avoiding the inclusion of the renal arteries or the renal vein in the aortic clamp but positive care has to be exercised that this is not done inadvertently. It is best to locate the renal arteries by a finger run up along each side of the aorta; this often obviates the need for dissection amongst

vascular tissue if an attempt is made to visualize these arteries.

It is worth giving brief mention to some of the worst technical difficulties that have been encountered in performing operations for aortic aneurysms, even though these were successfully overcome. Damage to the common iliac veins or the inferior vena cava remains clearly in mind as the most troublesome and unnecessary complication. If this should occur it must be remembered that it is easy to exsanguinate the patient into the sucker without there being any visible sign of blood loss apart from the rapid accumulation of blood in the sucker bottle. Lumbar veins crossing behind the aneurysm are commonly adherent to it and are extremely vulnerable if an instrument is passed behind the aneurysm. This manoeuvre should only be attempted with gentleness at the neck of the aneurysm and, rather than risk lacerating the lumbar veins by forcing a way through, an aortic clamp may be applied vertically from the front of the aorta without passing it behind the aneurysm. Certainly the renal vein may be easily damaged and like all large veins can be exceedingly difficult to control. This vein, however, is an easily recognized landmark that should be looked for and avoided as it is approached. It does in fact form the usual upper limit of dissection and there is little excuse for damage to it.

It is seldom that a bifurcated 'graft' cannot be anastomosed end-to-end with the aorta and the iliac arteries. The latter often show some aneurysmal change but this may be accepted and the expanded artery adapted to the prosthesis. If the iliac artery is too diseased for this to be suitable, the limbs of the prosthesis are drawn down to the common femoral arteries and anastomosed to the front of these; in this case the common iliac arteries are ligated or sutured.

There are two other technical points which should be discussed. The first is the use of anticoagulants. Our own practice is to inject 40 ml of heparin solution (50 mg in 500 ml saline) into the iliac vessels immediately after clamping the aorta. This prevents clotting in stagnant columns of blood below the clamps. This system has proved reliable and avoids the possible difficulties that general heparinization may cause, for example in the process of clotting the prosthesis to make it blood-proof. Many surgeons do, however, use general heparinization reversed with protamine at a suitable stage in the operation. Whichever system is used the patency of the iliac and common femoral arteries should be ensured before completing the lower anastomoses by temporarily unclamping the iliac vessels and demonstrating that sharp pressure over each groin produces a corresponding gush of blood back from the unclamped iliac artery. Heparin solution is then

re-instilled and the anastomosis proceeded with. Heparin should not be necessary postoperatively and indeed can be very dangerous. Long term anti-coagulants such as phenindione are not necessary or desirable.

The other technical point is the method of dealing with an aberrant renal artery taking off from the aneurysm and still patent at operation; this has occurred three times in the Oxford series of eighty-three cases. Obviously it is damaging to a significant proportion of the kidney to lose the circulation contributed by an aberrant artery. Fortunately it is not difficult to re-implant the artery into the front of the prosthesis. Sometimes it is clear that the major blood supply to the kidney arises from the aberrant position and this must certainly be re-implanted; the kidney can be protected from ischaemic damage whilst this is being done if it is perfused with chilled oxygenated blood through the detached artery.

Clearly the possible pitfalls are legion but some of the worst catastrophes have been mentioned. In at least half of the patients the operation is surprisingly easy and in the majority the long-term results are most gratifying.

False aneurysm due to trauma

The wall of a false aneurysm is composed of clot and the condition is caused by leakage of blood from a damaged artery. The trauma is usually due to a penetrating wound which partially opens the artery. A pulsating haematoma is set up which expands slowly, often over weeks, causing considerable pain by pressure on surrounding structures. The artery continues to function well in spite of the aperture in its side and a good pulse may be felt distally. Clearly this condition must be distinguished from a traumatic arterio-venous fistula. The presence of a pulsating tumour usually makes the distinction easy. However, sometimes both conditions may be present simultaneously. The nature of the trauma causing the condition may be very diverse and not necessarily due to a penetrating injury. For example, the brittle axillary artery of an elderly patient may be torn if the shoulder is dislocated or an exostosis may puncture an artery (Fig. 9).

Surgical treatment is usually quite simple and follows similar lines to those already described. The main artery is controlled at a higher level through a small incision or in some circumstances by a tourniquet. With the main artery occluded the aneurysm is boldly incised and the firm clot comprising its wall shelled away. Once this is removed the aperture in the artery, at this stage a smooth oval, is easily identified (Fig. 10a) and if necessary can be plugged with a finger. It is, however, no use attempting to repair the artery locally because the edges of the

FIG. 9. A false aneurysm due to laceration of the popliteal artery by an exostosis. An arteriogram has outlined the artery and a 'cloud' of the medium can be seen passing into the cavity of the false aneurysm.

aperture are covered with a thick deposition of new intima which will not allow suturing without severe distortion and narrowing of the lumen. It is necessary to trace the artery upwards and downwards a short distance until reasonably normal artery is reached, and at these sites the artery is divided and continuity restored by direct end-to-end anastomosis (Fig. 10b) or by bridging the gap with a reversed saphenous vein graft.

In conclusion, it is perhaps of interest to quote from a letter by Mr Lambert, surgeon at Newcastle-upon-Tyne, to Dr Hunter written in 1761 in which he describes a method of treating aneurysm caused by the practice of bleeding (Lambert, 1764).

'I had very carefully attended to the cure of three aneurysms, for which the operation was performed by my late worthy friend and colleague, Mr. Hallo-

FIG. 10. False aneurysm of 3 weeks' standing, due to high velocity fragment of metal. (a) Appearance after opening aneurysm and removing clot. The aperture in the wall of the artery has become a smooth oval due to deposition of 'new-intima'. (b) The damaged portion of artery has been excised and continuity restored by end-to-end anastomosis.

well. In one of them, after the operation was performed in the common way, by a ligature above and below the aperture in the artery, such violent pain, swelling, and inflammation, came on, as to threaten a gangrene. Bleedings, fomentations, poultices, etc. mitigated these symptoms; a plentiful suppuration ensued; the wound gradually healed, and the patient was discharged from the hospital with a weak arm, and a pulse much weaker in that wrist than in the other. This case, in particular, made me turn my mind to the operation for the Aneurysm, and made me wish to see it done with some alteration in the method, so as to make less disturbance in the circulation of the part. I recollected all that I had seen or read of the effects of styptics, of pressure, and of ligatures in the cure of haemorrhages. I considered the coats and motions of arteries, and compared their wounds with the wounds of veins and other parts. I reflected upon the process of nature in the cure of wounds in general, and considered in particular, how the union of divided parts was brought about in the operation of the hare-lip, and in horses'

necks that are bled by farriers. Upon the whole, I was in hopes that a suture of the wound in the artery might be successful; and if so, it would certainly be preferable to tying up the trunk of the vessel. I communicated my thought to Mr. Hallowell, Mr. Keenlyside, and some other friends of the profession. A case of an Aneurysm from bleeding occurred, and fell to Mr. Hallowell's lot. I recommended the method that I have hinted. He put it in execution June 15, 1759. Everything was done in the usual method, till the artery was laid bare, and its wound discovered; and the tourniquet being now slackened, the gush of blood *per faltum* showed there was no deception. Next, two ligatures, one above the orifice, and one below, were passed under the artery, that they might be ready to be tied at any time, in case the method proposed should fail. Then a small steel pin, rather more than a quarter of an inch long, was passed through the two lips of the wound in the artery, and secured by twisting a thread round it, as in the hare-lip. This was found to stop the bleeding; upon which the arm was bound up, the patient put to bed, and ordered to be kept quiet, etc. as usual in such cases. The wound was first dressed on the fourth day, viz. June 18. It looked well for the time, and continued to heal, without interruption in a kindly manner. The pin came away with the dressings June 29, that is on the fourteenth day; and on the 7th day of July every part was healed, except what was kept open by the two ligatures, which remained loose in the flesh like two setons. These were therefore removed. In a few days after this the wound was compleatly cicatrized: and July 19 the patient was discharged from the hospital perfectly well, and with a pulse in that arm nearly as strong as in the other. Indeed, the pulse was very little altered immediately after the operation; it was weakened in a small degree, as might be expected from the diameter of the vessel being straitened; but it was so strong and equal that we had not the least doubt of the blood's continuing to circulate freely through it.

If it should be found by experience, that a large artery, when wounded, may be healed up by this kind of suture, without becoming impervious, it would be an important discovery in surgery. It would make the operation for the Aneurysm still more successful in the arm, when the main trunk is wounded; and by this method perhaps, we might be able to cure the wounds of some arteries that would otherwise require amputation, or be altogether incurable.'

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Historical references

- AETIUS OF AMIDA (A.D. 502–272) *Librorum medicinalium tomus primus, primi scilicet libri octo nunc primum in lucem editi*. Venetiae, in aed. haeredum. A. Manutii et A. Asculani, 1534.
- BREASTED, J.H. (1930) *The Edwin Smith Surgical Papyrus*, 2 vols. Chicago University Press and Cambridge University Press.
- COOPER, SIR A.P. (1836) Case of a femoral aneurism, for which the external iliac artery was tied, with an account of the preparation of the limb, dissected at the expiration of eighteen years. *Guy's Hospital Reports*, 1, 43.
- COOPER, SIR A.P. (1836) Account of the first successful operation, performed on the carotid artery, for aneurism, in the year 1808; with the post-mortem examination, in 1821. *Guy's Hospital Reports*, 1, 53.
- COOPER, SIR A.P. & TRAVERS, B. (1818) *Surgical Essays*, Vol. 1, p. 101. Cox & Son, London.
- HOME, SIR E. (1786) An account of Mr. Hunter's method of performing the operation for the popliteal aneurism. *London Medical Journal*, 7, 391.
- LAMBERT, R. (1764) *Medical Observations and Inquiries by a Society of Physicians in London*, 2, 360.
- MATAS, R. (1888) Traumatic aneurism... incision and partial excision of sac; recovery. *Medical News*, 53, 462.
- MATAS, R. (1902) Aneurysmorrhaphy. *Transactions of the American Surgical Association*, 20, 396.

Modern references

- DE BAKEY, M.E. & COOLEY, D.A. (1953) Surgical treatment of aneurysm of abdominal aorta by resection and restoration of continuity with homograft. *Surgery, Gynaecology and Obstetrics*, 97, 257.
- DE BAKEY, M.E., CRAWFORD, E.S., COOLEY, D.A., MORRIS, G.E. Jr, ROYSTER, T.S. & ABBOTT, W.P. (1964) Aneurysm of abdominal aorta; analysis of results of graft replacement therapy one to eleven years after operation. *Annals of Surgery*, 160, 622.
- CARREL, A. (1908) Results of the transplantation of blood vessels, organs and limbs. *Journal of the American Medical Association*, 51, 1662.
- CRAWFORD, E.S., DE BAKEY, M.E. & COOLEY, D.A. (1959) Clinical use of synthetic arterial substitutes in 317 patients. *Archives of Surgery*, 76, 261.
- ESTES, J.E. Jr, (1950) Abdominal aortic aneurysm, study of 102 cases. *Circulation*, 2, 258.
- GRAHAM, A.L., NAJAFI, H., DYE, W.S., JAVID, H., HUNTER, J.A. & JULIAN, ORMAND C. (1968) Ruptured abdominal aortic aneurysm. *Archives of Surgery*, 97, 1024.
- SZILAGYI, D., EMERCIK, SMITH, R.G., DERUSS, F.J., ELLIOTT J.P. & SHERRIN, F.W. (1966) Contribution of abdominal aortic aneurysmectomy to prolongation of life. *Annals of Surgery*, 164, 678.
- VOORHEES, A.B. Jr, JARETZKI, A., III & BLAKEMORE, A.H. (1952) The use of tubes constructed from Vinyon 'N' cloth in bridging arterial defects. *Annals of Surgery*, 135, 332.