# Direct Operation for Intracranial Aneurysm: Some Technical Problems and Attempts at Their Solution*

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Intracranial aneurysms present neurosurgeons with some of their most frustrating problems. At first sight they appear to be simple anatomical abnormalities which are quite localized, and to invite a simple mechanical operation for their correction. Yet they can be among the most treacherous of all lesions that the surgeon meets. In this paper I wish to consider why this is so, discussing various technical problems and attempts at their solution.

It is important that we remember that all of these problems are quite recent in surgical history, for until 1934 the diagnosis of aneurysm was made on clinical grounds. Before that year it was commonly held that the portion of the internal carotid artery within the cavernous sinus was one of the most frequent sites for aneurysm, for diagnosis could be made easily because of the many clinical signs of a lesion surrounded by cranial nerves in that location. This background has left us with carotid ligation in the neck—the only procedure still commonly available for aneurysms in that site—as the historical basis of aneurysm surgery. The simple surgical teaching that arrest of haemorrhage, or prevention of recurrence of haemorrhage, is to be achieved by ligation of the bleeding point has since led us to direct intracranial attack on aneurysms as the logical procedure. I am grateful that this is my subject for today, for we have found carotid ligation in the neck to be dangerous with a high rate of complication and as significant incidence of early recurrent bleeding. We prefer direct approach whenever possible.

Before 1934, saccular aneurysms on the internal carotid artery above the cavernous sinus, or its branches, were rarely diagnosed, and operative approach to them was rarer still. The introduction of carotid angiography in that year by Egaz Moniz provided the diagnostic tool that was to change entirely our knowledge of this condition as well as of many other intracranial diseases. Even so it was not until widespread use of carotid angiography, especially by the percutaneous technique, in the early 1950's and of vertebral angiography even later, that surgery for aneurysm became at all common.

There was yet another factor which delayed the general availability of surgery to patients suffering aneurysm, which was lack of appreciation of the incidence of the condition. At first, attention was directed to congenital aneurysms as the cause of

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subarachnoid haemorrhage in young normotensive adults, and most diagnostic studies were applied to this group. However the comparative rarity of aneurysms found clinically, by angiography or at autopsy in children's hospitals has caused us to review our prevous ideas that these are congenital lesions. Even though they may occur at sites of structural weakness of vessels, and especially at bifurcations, saccular aneurysms do not often appear until late adolescence except in the presence of hypertension due to such lesions as coarctation of the aorta. Gradually it was appreciated that some patients with the apparent picture of a "stroke" had suffered intracerebral haemorrhage from an aneurysm, and that aneurysm is most common in association with hypertension in the fifth and sixth decades of life when spontaneous cerebral haemorrhage is also most frequent. Thus the search for aneurysm was extended from young normotensive patients with "unexplained" subarchnoid haemorrhage to all patients with "atypical" strokes.

This change in attitude came most rapidly in general hospitals where neurosurgeons were in close contact with their physician colleagues, and more slowly where neurosurgical institutes had been developed in isolation with admission by referral from general hospitals. This point struck me most strongly during a visit to the Neurosurgical Research Institutes of Moscow, Leningrad and Kiev in 1965 when I found that carotico-cavernous fistulae were more common than sacular aneurysms. I understand that this situation has changed to some extent since the appointment of a Professor of Neurosurgery at the Moscow Neurological Institute. Until recently I had accepted the commonly expressed view that aneurysm was a rare condition in Asiatic peoples, but the recent paper of Suzuki, Hori and Sakurai in the Journal of Neurosurgery indicates that the incidence in Japan is not as low as had been thought. It seems indeed that we have common problems.

One other factor of importance concerning the organization of neurosurgical practice should be mentioned. Experience of anerysms and especially of results of treatment will be influenced greatly by the manner of selection of patients. If admission to a neurosurgical unit is delayed until diagnosis is made and angiography has been performed, and is arranged selectively for patients who present as good surgical risks, results may be expected to be good. Where neurosurgeons work in general hospitals, a greater proportion of their patients will be seriously ill, with expected on their overall results. Concentration of cases within relatively few units will increase overall experience, but not necessarily the personal experience of individual surgeons. When aneurysm surgery is only occasional, results are unlikely to match those of surgeons familiar with the problem. For all of these reasons I distrust comparison of mortality rates for various methods of treatment from units whose referral routes, admission policies and staffing I do not know. Particularly do I have reservations about mass surveys such as the Comparative Study of Treatments for Subarachnoid Haemorrhage on these grounds.

Similar thoughts apply to investigation of the natural history of aneurysms, which is dependent upon sampling and upon policy with regard to angiographic and autopsy investigation of those patients who may have aneurysms. These are major obstacles to assessment of our problem and of the results of treatement. I should

say at once that my own Department is part of the Royal Brisbane Hospital so that many patients are referred to us for emergency management soon after admission. Some selection occurs in relation to other patients who are sent to Brisbane from over 1000 miles away in Queensland and nearly 2000 miles from Papua and New Guinea. Within the Department, the policies adopted with regard to management of aneurysms have always been consistent at any one time, although progressive changes in policy have been made over the years as the result of comparison of our experience with that of others. I shall refer to these various phases in relation to various problems.

I should now like to pass from these general aspects to consider particular problems which have been met in a personal experience of direct approach to almost 500 aneurysms in the past 16 years, together with observation of over 200 aneurysms operated upon by others in my department. Some of these problems I will illustrate from my series of 38 aneurysms of the vertebrobasilar system on which I have operated.

The first matter which I wish to discuss is management of the aneurysm itself. Most of the aneurysms which we see are saccular, but some are giant, expanding to take up the vessel of origin and its branches, and a few are fusiform in type. Experience has shown that the great majority of saccular aneurysms have narrow necks, except perhaps on the anterior communicating artery where broad-necked aneurysms are fairly common. This is true even of multilocular aneurysms, for the secondary loculi usually arise from small blebs, which are presumably the site of rupture in many cases and which tend to develop on the periphery of the aneurysm rather than the neck. This was not my view in my early days of aneurysm surgery, but more bold dissection of aneurysms under conditions of magnification and induced hypotension to which I will refer later, has proved it true. Some special tricks aid identification of a neck: large aneurysms may be gently rotated to collapse the sac; thrombosed sacs, or sacs that are large enough to obscure vision may be excised to give a better view; the fundus of the aneurysm may be opened and the opening placed in a sucker to relieve lateral pressure causing distension; a ligature may be placed distal to the neck to collapse the aneurysm and display the neck more clearly. With the help of these techniques it is nearly always possible to occlude the neck with precision, usually by a clip, although the advantage of a ligature, passed if necessary by the technique illustrated, should not be forgotten where clip placement is difficult. On some other occasions it is an advantage to excise the fundus of the aneurysm before clipping the neck, especially in the case of the common aneurysm of the internal carotid artery at the level of the posterior communicating artery. This aneurysm is usually attached to the free edge of the tentorium so that attempt to clip its neck without first dividing it may lead to splitting of the neck due to tension. Prior division of the aneurysm obviates this risk. Similarly false sacs which tether the aneurysms to the brain are often best excised early to permit full dissection without tension.

When a saccular aneurysm has an expanded neck it may be possible by torsion of the aneurysm to reduce the size of the neck sufficiently for a clip or a ligature to be applied without narrowing or kinking the parent vessel or branches. On other

occasions, multiple clips placed "end on" to the aneurysm neck, with or without prior excision of the sac, may suffice. Failing this, expendable vessels such as the anterior communicating artery when there are two good anterior cerebral arteries, the posterior communicating artery, or the proximal portion of a posterior cerebral artery may be clipped with the aneurysm. At other times one may decide deliberately to sacrifice a vessel without collateral supply: the best example is the anterior termporal artery when it is included in an aneurysm at the first bifurcation or trifurcation of a middle cerebral artery, for its occlusion produces no significant deficit. This is a veriety of the "trapping" operation.

Of great importance is the careful preservation of small vessels which may be closely related to the aneurysm neck, for aneurysms may often develop at the origin of small vessels rather than at major bifurcations. The anterior choroidal artery should be carefully preserved both with aneurysms at its origin and with aneurysms at the level of the posterior communicating artery, for occlusion of this vessel may result in profound unconsciousness, hemiplegia, hemianopia and death. When this vessel is replaced by a choroidal leash from the posterior communicating artery the same dangers apply to occlusion of that vessel. In the same way small vessels at the carotid bifurcation and origin of the middle cerebral artery must be preserved, and the recurrent artery of Heubner, or medial perforator, requires great care in anterior cerebral or anterior communicating aneurysms. Similar care is needed at the basilar bifurcation for the posterior perforating arteries and the posterior choroidal vessels may not be expendable.

Many of these vessels can be identified in good angiograms, and should be searched for to allow proper planning of operation of operation. Good operating conditions that allow easy manipulation and full dissection of the aneurysm are essential to the preservation of these small vessels.

Experience has shown that it is possible to deal with almost all saccular aneurysms definitively without to muscle wrapping or investment in reinforcing plastics. Our objective is to restore the parent vessel to normal lumen at the site of aneurysm so that the lateral pressure on its walls is reduced to normal level. This is important to prevent recurrence of the aneurysm from the base of its neck, and for this reason the clip is placed as close as possible to the vessel.

Fusiform aneurysms are fortunately rare, for they are difficult to deal with except by excision but investment in plastic seems a resonable alternative.

Complex and giant aneurysms may sometimes be treated by proximal ligation of a vessel such as the dominant anterior cerebral artery in case of an anterior communicating aneurysm, though we have not favoured this technique for small saccular lesions. Giant aneurysms may lend themselves to the pilo-injection techniques of Gallagher or to Mullen's techniques for precipitating thrombosis. A difficulty is that many giant aneurysms already are extensively thrombosed and produce disability by acting as tumours. Attempts to remove the clot and to collapse and clip the neck in these lesions are full of danger, for the tissues of the neck do not take clips or ligatures well and may split into the parent vessel. Possibly microsurgical suture of the base of the aneurysm may prove useful in the future.

The next subject which I wish to discuss concerns the local circumstances under which the aneurysm should be manipulated and clipped or ligated. With normal intravascular pressure, the tension in the wall of an aneurysm is exceedingly high and the risk of rupture during surgery is great. For this reason I at first used bilateral exposure of the carotid arteries, and, on occasion of the vertebral arteries, in the neck so that these vessels could be occluded, partially or even totally, for the brief period of final aneurysm dissection. Later we used proximal occlusion of the parent vessel during the later stages of dissection. A simple clip was made by modifying a hairdressing clip and had the advantage that the tension of its spring was readily adjusted by bending the wings of the clip. It was applied with just such tension that flow was greatly reduced without collasping the vessel completely, since stronger clips often damaged the vessel wall. This technique is still sometimes used early in the dissection of middle cerebral and basilar aneurysms, and temporarily when haemorrhage occurs before the field is prepared. However such clips involve increased trauma to the vessels and may increase the risk of postoperative spasm, so that their use has become less frequent. Instead we have followed the advice of Drake, and now induce hypotension at levels of 40–60 mmHg at the time when aneurysm dissection is imminent. Our chief anaesthetist, Dr. Tess Brophy, is very expert in achieving this level rapidly with a combination of posture, hyperventilation and intravenous trimetaphan in small dosage and restores normal levels quickly. The advantages of this technique must be experienced to be believed for the aneurysm becomes completely flaccid and is dissected and manipulated quickly and comfortably. We have been able to maintain induced hypotension at these levels for as long as 20 minutes after-effect even in hypertensive patients.

When we first used temporary arterial occlusion, over 200 patients were operated upon under conditions of moderate hypothermia at 28°–30°C, for hypothermia was believed desirable to permit prolonged occlusion of vessels. With increasing practice the time necessary for dissection of the aneurysm became so brief that hypothermia was not needed, and this is particularly true with the use of induced hypotension. For these reasons we have abandoned induced hypothermia with its associated risks althogether in the last 2 years for aneurysm surgery, although I would still use it for more complicated vascular surgery, especially by microsurgical techniques, when necessary. We have found no reason to subject the patient to the added risks of profound hypothermia with cardiac by-pass, and I doubt the place of these techniques for dealing with aneurysms.

May I pass next to the question of exposure of the aneurysm. I believe first that the most critical issue in dealing with supratentorial aneurysm is the proper design of an adequate exposure extending right to the base of the skull. For anterior cerebral and anterior communicating lesions our flaps usually cross the midline to permit division of the falx, which gives the surgeon a choice whether he will go under the frontal lobe or medially down the great cerebral fissure, according to the direction of the aneurysm and the shape of its neck. On occasion, internal carotid aneurysms are approached through trephine discs, but I prefer an exposure directed down the sphenoidal ridge. For sick patients with intracerebral haematomas a small subtem-

poral decompression may suffice to approach a middle cerebral lesion.

For aneurysms of the basilar bifurcation, the upper part of the basilar trunk and the posterior cerebral artery we use an approach under the temporal lobe centred above the ear, with division of the tentorium if necessary, with proper care of the abducens and trochlear nerves, the ambient cistern is opened and the posterior cerebral and superior cerebellar arteries are dissected medially. It has been possible to divide the vein of l'Abbe when necessary without serious trouble in most patients, but venous infarction and swelling is a risk. Vertebral aneurysms are approached by a lateral hockeystick incision similar to that which we use for auditory neuromas, with the patient sitting. Aneurysms low on the basilar trunk, or at its origin, are approached through the basi-sphenoid and basi-occiput by an anterior approach. It seems that the route through the mouth provides better access and less difficulty than the submandibular approach which I have used.

The second problem in approach is to provide room for full exposure. This depends primarily upon posture, and expert anaesthesia. We operate with the patient's head raised to aid venous drainage and anaesthesia is induced with thiopentone and maintained with controlled ventilation, nitrous oxide and oxygen, and curare. Our aim with ventilation is to achieve normocapnia—a negative phase is rarely neccssary with abdominal relaxation and is contraindicated when the patient is sitting. Infusion of osmotic diuretic agents—mannitol is our choice—and drainage of cerebrospinal fluid then usually provide enough room. In our experience, hydrocephalus is very common soon after subarachnoid haemorrhage due to outpouring of cerebrospinal fluid in reaction to the blood. In the case of basilar bifurcation aneurysms in particular there may also be obstruction of the ambient cisterns by blood clot. We therefore aspirate the ventricles early and open the basal cisterns widely to evacute cerebrospinal fluid. On occasion a lumbar cannula is used to maintain drainage.

Additional space may sometimes be obtained by early aspiration of a subdural or an intracerebral haematoma. If space is inadequate we do not hesitate to excise a frontal pole or a temporal pole, or part of a cerebellar hemisphere to give better access. At the end of operation any traumatized or infarcted areas of the frontal and temporal poles should be excised to prevent post-operative swelling, and the bone plate left unsecured or removed in case of doubt about post-operative pressure.

The next subject that I should like to consider is the general management of the patient. I shall not do more than refer to the importance of attention to the patient's respiratory physiology, but must comment upon the question of fluid and electrolyte balance. Our patients who suffer subarahnoid haemorrhage often have great changes in their serum electroytes: hyponatremia and hypokalemia are quite common and these problems may be increased by osmotic diuretics and by hypothermia if this is used. We therefore study electrolyte levels with care and base our therapy on physiological solutions rather than normal saline. To avoid postoperative oedema we utilize isosmotic solntions such as Hartman's solution in 5% dextrose as well as simple isotonic solutions such as glucose-saline.

Unfortunately, I have no method to control the occurence of cerebral vascular

spasm, either pre-operatively or post-operatively. Minimal brain retraction and minimal interference with vessels at operation is obviously desirable and the lumen of the vessel should not be narrowed by an aneurysm clip. Postoperatively we deliver high concentrations of oxygen by nasal catheter or cannula, or an M. C. mask. When cerebral blood flow appears in doubt, we use low molecular weight dextran daily, for we believe it may be helpful, but we avoid this when haemostasis appears doubtful from surgical truma during operation. Dexamethasone is also given and appears to help in some marginal cases but obviously cannot be effective in areas of infarction and swelling.

May I now discuss the selection of patients for surgery. When an aneurysm presents as a cerebral tumour, it should be dealt with on its merits as is any other tumour. Sometimes aneurysms may present by sudden enlargement without haemorrhage, particularly at the origin of the posterior communicating artery causing an isolated oculomotor nerve paralysis, sometimes with referred pain in the ophthalmic division of the trigeminal nerve because of their dural attachment. Aneurysms of the posterior cerebral artery may produce a similar syndrome. Once such an aneurysm has enlarged suddenly, the risk of a future subarachnoid haemorrhage is greatly increased, and the likely time interval before this haemorrhage is the same as if the first presentation was due to haemorrhage. There is therefore some urgency in dealing with the aneurysm which at the stage of expansion only produces no special problem of morbidity or mortality.

The real problems arise with the usual presentation of aneurysms by haemorrhage as the first event. Selection of patients in this group is made first in the knowlege that operation is usually prophylactic only, rather than therepeutic. When prophylactic surgery only is to be offered, the important criterion is that the general health of the patient (as distinct from illness caused by the aneurysm) must be good enough to support surgery of this magnitude, and the general life expectancy is great enough for prophylactic surgery to be attempted. We have no set limits of chronological age, for some patients aged 70 are more suitable than others aged 50-we are only more cautious with patients over 60 years. Hypertension is so common in these patients, especially with basilar aneurysms, that we do not exclude patients because of it alone unless hypertension is extreme and unable to be controlled medically. However hypertension is taken into account when grading pateints for consideration. Respiratory function and reserve is particularly studied.

When these general criteria are satisfactory, our policy has been to advocate surgery whenever the aneurysm is technically operable and the grade of illness is suitable.

Patients are graded on the usual criteria of state of consciousness, neurological deficit, decrebrate reactions, vegetative disturbances, and degenerative cardiovascular disease. Grades 1, 2 and 3 are accepted for surgery readily, grade 4 with great caution as to timing, and grade 5 not at all unless there is a space occupying haematoma. In the early years of my department after 1956 surgery was offered to all patients, but experience soon showed that results in grade 4 and 5 seldom justified operation.

Timing of surgical intervention is recognized to be of critical importance. If

operation is delayed, further haemorrhage may occur, most commonly on the 7th to 10th day. If operation is too early there may not have been time for cerebral vasospasm to subside. In the early years of my department we operated upon all patients as soon as convenient, sometimes on the day of admission. Analysis soon showed that our mortality rates were too high. We then developed, for several years, a consistent policy of operating on the 5th day after haemorrhage, and then analysed our results. It was apparent that this timing produced good results in grades 1 and 2, but often unsatisfactory results in lower gradings. From this experience our present policy developed, based on the assessment of the individual patient in relation to our understanding of the effects of subarachnoid haemorrhage, and especially vascular spasm. Perhaps I might speak now about these concepts.

When haemorrhage first occurs from an aneurysm it is usually of minor degree into the subarachnoid space. Arrest of haemorrhage occurs rapidly by the usual method seen anywhere in the body-contraction and retraction of the bleeding vessel. This local condition we refer to as local vascular spasm, which we see as a friend rather than as an enemy. There may result some degree of ischaemia of the cerebral territory of supply of that vessel, accounting at times for dulling of mentality or focal neurological signs. Coagulation within and over the bleeding point on the aneurysm then secures arrest of haemorrhage, as elsewhere in the body, and the vessel commonly relaxes. In the particular environment of the cerebral vessels, organization of the thrombus may be delayed and interrupted by fibrinolysins until after normal pressure has been restored. Any temporary elevation of blood pressure, even during R. E. M. sleep, may then cause further haemorrhage through the soft clot which may be adherent to softened overlying brain so that intracerebral haemorrhage may occur. The objective is to time operation to take place just when then the vessel is beginning to relax, which is the time at which the symptoms and signs of partial local ischaemia are disappearing. Thus we aim to operate upon the patient as soon as he is clinically improving.

In practice therefore we study the angiograms for evidence of focal spasm and watch the patient's progress. Grade 1 patients are operated upon at any time after 48 hours-72 hours and then on the first convenient operating list. Grade 2 pateints are operated upon as soon as they improve-usually at about 5–7 days.

In the lower grades, several complicating factors may be present. The first is severe and persistent local spasm for which we cannot although some may suffer repeated small haemorrhages. If we have evidence of repeated bleeds, or if rebleeding occurs early, then we operate as soon as convenient for in these patients further bleeding may be expected. Otherwise we await clinical improvement for longer periods and often into the second week for Grade 3 patients. The second complication is widespread vasospasm that persists. We do not know why this should occur in spontaneous subarachnoid haemorrhage since it is rare when haemorrhage occurs during other neurosurgical procedures. We suspect that brief widespread spasm is common after subarachnoid haemorrhage and that loss of consciousness which may be only transient is due to spasm of the basilar artery. When severe depression of consciousness contiunes, or widespread vasospasm is seen at angiography, we commonly repeat the angiogram at an interval to help assess when spasm is subsiding

before opertion is undertaken. Studies of regional blood flow by radioisotope techniques may be developed to aid this assessment. The third complication is acute hydrocephalus that may warrant drainage operations to improve the patient to a state fit for surgery. The fourth complication is a life-threatening subdural or intracerebral haematoma, and we have had a surprising number of successes after removing these lesions uregntly. Otherwise patients in Grades 4 or 5 are treated conservatively and operated upon only if they improve to better grades. Persisting tachycardia is an ominous sign.

In pursuring such a policy of delay in some cases, we are aware of the risk of recurrent haemorrhage. To wait longer would give better results in those who survived to operation, with better surgical figures, but a greater number of deaths overall. What is needed is a means of relaxing vasospasm electively at the time of operation, or a means of preserving the strength of the thrombus. The use of antifibrinolysins, and especially epsilon-aminocaproic acid, appears from the work of Mullan to be promising, although we have no experience of it as yet.

Equally important is the stage at which the patient first reaches neurosurgical care, and the timing of angiography. Our undergraduates and junior resident staff must be taught clearly that any sudden, severe, unusual and unexplained headache may be due to subarachnoid haemorrhage, and when accompanied by even minor neck stiffness and photophobia warrants consideration of lumbar puncture. Too often do we see patients only after a second more severe haemorrhage.

Transfer of patients from a distance is safest when they are ill, for protective vasospasm is still present.

Angiography, in our opinion, should be done as soon as possible after the diagnosis of subarachnoid haemorrhage has been confirmed. With proper attention to airway and respiration, avoidance of excessive premedication, small volumes of dye and reasonably low pressure injection, we have not seen deterioration due to angiography alone. The surgeon can then determine whether urgent operation is needed, or plan an elective operation while the patient is prepared.

Our policy is to study all four vessels if necessary, but often to stop when an aneurysm that is the cause of haemorrhage has been found. Criteria for deciding that a particular aneurysm has bled include clinical localization, shape and size of aneurysm, evidence of local haematoma and presence of vasopsm. When multiple aneurysms are found, more than one may be dealt with at one operation through a single approach.

The effect of these practices may best be indicated by the results which I shall not present in detail for the reasons I have stated earlier, but merely outline.

| Grade | Mortality Rate |
|---|---|
| 1 | 5% |
| 1 and 2 | <10% |
| 3 | 20% |
| 4 and 5 | 50%+ |
| Overall | 15% |

It is believed that these results are significantly better than those of conservative treatment, and they are improving steadily. The effect of increasing experience may be soon from my aneurysms of the vertebrobasilar system, where I started from little background of guidance from the literature or experience of others.

| | Vertebrobasilar Aneurysms | | |
|---|---|---|---|
| | Alive | Dead | Total |
| 1958–60 | 3 | 6 | 9 |
| 1961–63 | 6 | 4 | 10 |
| 1964–66 | 7 | 2 | 9 |
| 1967–70 | 7 | 3 | 10 |

The last period includes one patient in Grade 4 with major technical difficulty and two in Grade 3.

Thus I have reported the major trends in my experience of 500 direct approaches to aneurysm, to indicate the gradual development of the policies we now adopt and our attempts at solution to many problems. We have followed many incorrect courses and introduced several complicated techniques only to return to a simpler policy based upon ordinary surgical principles, bold and meticulous dissection under magnification and induced hypotension, careful assessment and preparation of each patient, individual timing of operation, and continuing analysis of our results.

It is my hope, Mr. Chairman, that my account of this experience may be of some interest and service to you and to the members of the Japan Neurosurgical Congress.