Surgical approach to giant intracranial aneurysms

Operative experience with 80 cases

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The authors report experience with the surgical management of 80 giant intracranial aneurysms (> 2.5 cm in diameter) during a 10-year period in which they performed 594 operations for aneurysms. The overall incidence of giant aneurysms was 13% but varied according to location: 20% of aneurysms of the internal carotid artery (ICA); 13% of middle cerebral artery (MCA) aneurysms; 1% of anterior cerebral artery (ACA) aneurysms; 15% of aneurysms of the basilar artery caput (BAC); and 18% of vertebrobasilar trunk (VB) aneurysms. Twenty-five patients had a subarachnoid hemorrhage (SAH), 49 had mass effect from the aneurysm, and six had ischemic events. There was no apparent difference in results related to the presence or absence of an SAH. Poor results were attributable to the operation except in the two cases of ACA aneurysm in which preexisting dementia persisted. Mortality was 4% and morbidity was 14%, varying from a combined low morbidity-mortality of 8% for ICA lesions to a high of 50% for BAC aneurysms. During the period of the study, different techniques were developed in an attempt to lower the risks of surgery. Ultimately ICA aneurysms were monitored with cerebral blood flow measurements and electroencephalography before and after temporary ICA ligation, then approached following resection of the anterior clinoid or treated with bypass in combination with ICA ligation. Aneurysms of the MCA were either opened during temporary MCA occlusion or resected in combination with a bypass procedure. Bypass grafts and circulatory arrest with extracorporeal circulation may have a role in giant aneurysms of the posterior circulation.

KEY WORDS ・ giant aneurysm ・ internal carotid artery ・ middle cerebral artery ・ basilar artery ・ anastomosis

ANEURYSMS greater than 2.5 cm in diameter are, by convention, classified as giant aneurysms. The review of Morley and Barr includes early major references, and the report by Sonntag, et al., summarizes more recent work. Drake and Yaşargil and Smith have reported their experience. These studies, and a number of other well documented case reports, illustrate the individual characteristics of giant aneurysms. It seemed appropriate to review the techniques, results, and complications of the surgical management of giant aneurysms in our hands.

Clinical Material and Methods

Case Material

From April, 1969, to April, 1979, the authors or a member of the resident staff with one of the authors acting as first assistant, performed 594 operations for intracranial aneurysms (70% were collected after July, 1974, the approximate time that superficial temporal artery to middle cerebral artery (STA-MCA) bypass surgery became an accepted procedure at this institution). Multiple aneurysms approachable through the same operative exposure were repaired routinely during the same operative procedure. Cases have been classified according to the aneurysm that bled or that was symptomatic, and the second aneurysm does not appear in the statistics (approximately 15% of cases have had multiple aneurysms and approximately 10% have had more than one aneurysm repaired at one operation). Of these 594 symptomatic aneurysms, 80 were giant aneurysms, and these aneurysms are the subject of this report.

Location of Aneurysm

Five locations were used for a general analysis of the case material: internal carotid artery (ICA),
middle cerebral artery (MCA), anterior cerebral artery (ACA), caput of the basilar artery (BAC), and vertebrobasilar trunk (VB). Aneurysms of the ICA were further subdivided into cavernous sinus, clinoid, and bifurcation aneurysms.

Clinical Recovery

Four categories were used for judging the result of surgery: 1) excellent: normal employment, with normal mentation and little or no neurological deficit; 2) good: neurological deficit but with normal mentation and employment; 3) poor: anything less than full activity (including patients with personality or mental change or a disabling focal deficit, or both); and 4) death. In determining the surgical morbidity and mortality, we chose an arbitrary end point of 6 months from the time of operation and accordingly any death within 6 months is reflected in the mortality figure.

Ischemic Complications

A lateralizing hemispheric neurological deficit, unrelated to a localized intracerebral hematoma, was considered to be ischemic in origin. These deficits were grouped into immediate and delayed forms. In the former group, the patients awoke from anesthesia with a new neurological deficit, not present before the operation. In the latter group, the patients awoke from anesthesia unchanged from their previous state, and a focal deficit subsequently developed. A deficit was not considered to be delayed unless it developed at least 4 hours after the time of operation.

Blood Flow Studies

Cerebral blood flow (CBF) was determined during the operative procedures from the clearance rate of xenon-133 (133Xe) which was injected into the cervical ICA. The CBF was correlated with simultaneous electroencephalograms (EEG). The methodology for these studies has been described previously. All CBF measurements were performed under general anesthesia at normocapnia (PaCO₂ = 40 torr).

Illustrative Cases

Case 1

This 47-year-old woman was admitted to St. Mary's Hospital on November 12, 1978, for evaluation of progressive failing vision in the right eye. In addition to a right inferior arcuate field deficit, the patient complained of right retro-orbital pain. A computed tomogram (CT) demonstrated a large suprasellar mass in the right clinoidal area. Cerebral angiography demonstrated a giant aneurysm arising from the right ICA (Fig. 1 upper).

Surgery was performed under general anesthesia and monitored with 133Xe CBF measurements and a continuous EEG for the initial phase of the procedure, the exposure of the cervical ICA. Blood flow fell from a baseline level of 90 to 40 ml/100 gm/min with temporary occlusion of the ICA. The EEG remained normal. It appeared that, if necessary, the patient would tolerate ICA ligation or trapping without STA-MCA bypass. The wound in the neck was left open for control of the ICA, the CBF probe and EEG leads were removed, and the right ICA aneurysm was exposed using the pterional approach. The anterior clinoid process was resected and the dura overlying the ICA incised and dissected anteriorly with the tip of a No. 11 blade knife to expose the anterior limits of the base of the aneurysm. At this point a tear developed in the base of the aneurysm which produced modest bleeding, and accordingly the ICA in the neck was temporarily ligated. A heavy-duty McFadden clip was placed across the base of the aneurysm, which seemed compressible, and although the bleeding was appreciably reduced, it was not completely controlled. A long Drake clip was placed across the aneurysm distal to the McFadden clip and it also failed to totally arrest the bleeding. Subsequently, we defined the source of the bleeding as a hole in the medial wall of the aneurysm distal to the point of clip application. The clip was repositioned on several occasions with and without temporary ligation of the ICA in the neck, and we were still unable to arrest the bleeding completely until a heavy Drake clip was placed across the tips of the McFadden clip. This "piggyback" clip produced enough tension to occlude the neck of the aneurysm. The aneurysm was approximately 2.5 × 3.0 cm in size. After the aneurysm was clipped, we were able to identify the pituitary stalk, the left optic nerve, the chiasm, and the left optic tract. The right optic nerve appeared to be in good condition but may have been traumatized at the time of the anterior clinoid resection as the aneurysm had eroded the lateral inferior wall of the optic canal.

The patient made an uncomplicated postoperative recovery except for persisting right retro-orbital headaches and a visual deficit in the right eye. Postoperative angiography (Fig. 1 lower) demonstrated occlusion of the aneurysm. In reply to a follow-up inquiry 3 months after surgery, the patient reported that she had returned to normal activities, the headache was gone, and the vision in her right eye was approaching normal.

Comment

The aneurysm, although thick-walled and difficult to obliterate, was not partially thrombosed and did not have an atherosclerotic base with areas of calcification. Accordingly, it was possible to preserve the lumen of the parent artery because the aneurysm did not tend to displace the clip and slide it onto the parent artery. If an aneurysm is compressible and appears to have a texture similar to a normal artery, it can usually be clipped.
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Case 1

FIG. 1. Case 1. Upper: Preoperative angiogram, anteroposterior view (left) and lateral view (right), showing a giant carotid-ophthalmic aneurysm. Lower Left and Lower Right: Postoperative angiograms, 1 week after surgery. Note the multiple clips applied in “piggyback” fashion.

Case 2

This 48-year-old woman underwent surgery in December, 1977, for a giant aneurysm of the right ICA that was producing a visual field deficit in the right eye (Fig. 2 upper). She had a coexisting large aneurysm of the left ICA. Cerebral blood flow in the right hemisphere fell with temporary ICA ligation from a baseline of 50 ml/100 gm/min before occlusion to less than 7 ml/100 gm/min with occlusion, and there was a major change in the EEG. It was thought unlikely that a bypass procedure would sustain the hemisphere and that the integrity of the ICA was necessary. Accordingly, the aneurysm was exposed by the pterional approach and the base isolated after the anterior clinoid process had been resected. The base of the aneurysm was pliable, and the aneurysm was clipped with a heavy McFadden clip. It was soft and nonpulsatile and, after clipping, the jaws of the aneurysm clip remained tightly closed as the blood pressure was elevated to hypertensive levels.

Two weeks after the operation the patient developed a bruit behind the right eye but remained neurologically normal. An angiogram (Fig. 2 lower left) demonstrated compression of the ICA at the site of repair, apparently related to the loss of turgor in the base of the aneurysm with flexion of its dome and deformation of the artery from the retroflexed aneurysmal mass. The bruit persisted for 1 week then disappeared. The left ICA aneurysm was successfully repaired 6 months later. Angiograms following that surgery demonstrated a normal right ICA without evidence of compression from the aneurysm (Fig. 2 lower right). Visual fields had returned to normal except for the presence of a small peripheral quadrant defect in the right eye.

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Case 2

Upper: Preoperative angiogram, showing a giant carotid-ophthalmic aneurysm. Lower: Postoperative angiograms, subtraction films. Lower Left: Two weeks after surgery, performed to evaluate a retro-orbital bruit. Note compression of the internal carotid artery (ICA), apparently caused by retroflexion of the aneurysmal mass. Lower Right: Six months after surgery. The ICA has now returned to a normal caliber.

Comment

This case illustrates an unusual type of postoperative vascular narrowing unrelated to the type seen with a recent subarachnoid hemorrhage (SAH). It remained focal and did not alter CBF appreciably, that is, CBF was not reduced below the critical level required for adequate hemispheric perfusion. The etiology of this transient constriction remained undetermined but was assumed to be mechanical in origin. Had we aspirated the aneurysm, the compression might have been prevented.

Case 3

This 52-year-old man underwent surgery in March, 1978, because of symptomatology related to the mass effect from a giant aneurysm of the left MCA (Figs. 3 and 4). The operative plan had been to open the aneurysm and convert its base to a pliable neck. This proved to be impossible because the vascular channel...
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was surrounded by thrombus and there was no endothelialized base to convert to an arterial lumen. Accordingly, a double STA-MCA bypass was performed. The MCA was occluded distal to the site of the striate vessels but proximal to the aneurysm, and then the lesion was resected. The patient awoke with a right hemiplegia, but within 12 hours speech and voluntary motor function had returned. He has since returned to employment, has normal speech and, except for a right-sided foot drop, normal neurological function. He has not been able to resume full employment as a roofing contractor. Postoperative angiograms have demonstrated good filling of the left MCA complex through the bypass graft (Fig. 5).

Comment

This type of complication is obviously unrelated to blood in the cerebrospinal fluid (CSF). It is typical of a group of complications classified as immediate ischemic complications. It demonstrates the very significant quantities of blood flow which can be obtained from bypass grafts and the importance of preserving the STA.

Case 4

This 48-year-old school teacher noted impairment of vision in her left eye in January, 1978. Her visual deficit was progressive, and within 3 months she was no longer able to continue teaching. Angiograms demonstrated a giant aneurysm of the left ICA, and the patient was referred for ICA ligation with STA-MCA bypass.

During surgery on March 28, 1978, CBF fell from a baseline of 60 to 30 ml/100 gm/min with temporary ICA ligation. It appeared that ICA ligation would be tolerated if augmented with STA-MCA bypass. We elected to place a Silverstone clamp on the ICA, and the anterior branch of the left STA was anastomosed to the angular branch of the left MCA through a trephine opening in the posterior temporal area. This
FIG. 6. Case 4. Preoperative computerized tomograms. The aneurysm appears much larger than on the angiogram (not illustrated).

decision was based on the appearance of the aneurysm on CT, which suggested a thick-walled lesion with partial thrombosis (Fig. 6).

The Selverstone clamp was advanced to total occlusion over a period of 3 days. The retinal artery pressures (RAP's) on March 29, 1978, the day the clamp was closed, were 64/18 on the left, 101/30 on the right. The patient was discharged on April 5, 1978, neurologically unchanged from her state at the time of hospital admission.

She returned 3 months later for re-evaluation. A good pulse was palpable over the site of anastomosis, RAP's were equal (90/40 each eye), and her visual impairment was unchanged. Angiograms demonstrated filling of a partially thrombosed giant aneurysm through the Selverstone clamp and patency of the STA-MCA bypass graft (Fig. 7). It was clear that additional measures were indicated and, because of the severe visual impairment and the need to eliminate the mass lesion, we decided to attempt direct repair and/or resection of the aneurysm.

The CBF measurements, during the initial stage of the operation on June 9, 1978, before and after temporary ICA ligation, were 60 and 45 ml/100 gm/min, respectively, indicating an increase in the occlusion CBF when compared to those values obtained during the operation in March. The ICA had achieved recanalization through the site of the clamp by a process of compensatory degeneration in the wall of the artery. After the clamp had been removed, it was necessary to resect the atrophic section of the vessel in order to preserve its integrity.

The aneurysm was then explored along the sphenoid wing, modifying slightly the pterional approach to avoid injury to the bypass grafts. After resection of the anterior clinoid, the base of the aneurysm was exposed and found to be indurated, irregular, and approximately 1.5 mm in diameter. Nevertheless, it was possible to place a long Drake clip across the base without deforming or encroaching upon the parent artery. The jaws of the clip were reinforced with two McFadden clips but this did not prevent the opening of the jaws of the clip with each systole. Only when the ICA was occluded did the jaws remain closed; therefore, the ICA was ligated and the aneurysm resected.

The patient made a swift postoperative recovery. Two months later her vision had improved sufficiently to allow her to return to employment.

Comment

This case illustrates several points of interest: the apparent reliability of the CBF measurements in predicting the tolerance to ICA ligation, the recanalization of a vessel through the carotid clamp,
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Fig. 8. Sketch of surgical procedure for an internal carotid artery (ICA) aneurysm. A: Scalp incision crosses but does not cut the anterior limb of the superficial temporal artery. The vessel must be preserved for possible bypass (see text). B: The pterional approach is used for ICA and middle cerebral artery aneurysms. The temporalis muscle is incised along its insertion onto the lateral orbital rim and retracted posteriorly without injury to the primary muscle belly. This prevents atrophy of this muscle and an unsightly postoperative cosmetic defect. C: A small craniotomy is augmented by sphenoid wing resection and temporal craniectomy. The temporalis muscle is subtotally partially incised along the zygomatic arch (incision diagrammatically exaggerated here) and retracted posteriorly. D: The dura is opened along floor of frontal fossa and tacked over sphenoid wing. This will be subsequently closed with small dural graft or piece of fascia lata. E: Typical giant aneurysm. Note the stretching of the A-1 segment of the anterior cerebral artery. The aneurysm must not be manipulated as the origin of this vessel can be torn. F: The dura is incised over the anterior clinoid process. G: The anterior clinoid is resected with a diamond burr. H: The dural sheath of the ICA is incised with a No. 11 blade knife. The bone is sealed with bone wax, and the cavernous sinus with a collagen preparation. I: The aneurysm is clipped after its base has been dissected away from adjacent structures. J: The aneurysm is aspirated.

the usefulness of the CT scan in the preoperative analysis of the lesion, the remarkable potential for recovery of the optic nerve from incomplete lesions, and the need for a stronger clip.

Surgical Techniques
Anterior Circulation Aneurysms

Giant aneurysms of the ACA are rare and will not be considered here. In ICA aneurysms we have routinely isolated the cervical ICA for: 1) EEG tracings and CBF measurements before and after temporary occlusion of that vessel, and 2) control of that vessel during an intracranial approach in those cases in which this is the treatment of choice. Controlled CSF drainage (removal of ± 60 ml) is useful for ICA aneurysms but unnecessary for aneurysms arising from the MCA. Excessive removal of CSF is to be avoided, as this tends to break bridging veins.

Aneurysms of the ICA or MCA have routinely been exposed through the pterional approach (Fig. 8 A-E). The scalp flap has been designed to preserve
both the anterior and posterior branches of the STA (Fig. 8 A). There is considerable variation in the location and size of these two branches and, therefore, the scalp incision varies slightly from case to case. Not infrequently it is necessary to dissect the anterior branch of the STA from the scalp flap before turning the latter.

It is necessary to remove the anterior clinoid process to expose giant aneurysms arising from the proximal ICA. The dura is initially cauterized, and then incised (Fig. 8 F). This permits resection of the clinoid process with a diamond burr (Fig. 8 G). In using the air drill one must be certain that cotton strips or other foreign materials are not present to become wrapped around the end of the drill bit (a complication that converts a microsurgical instrument into a high-speed egg beater). The Yasargil self-retaining retractor protects both the patient and the surgeon from this transgression. There is considerable variation in the length of the clinoid process; usually one must remove 3 to 4 mm before the proximal limit of the aneurysm base can be identified. Invariably there is brisk bleeding from the cavernous sinus, but hemostasis with bone wax and one of the collagenous hemostatic agents is not difficult.

After removal of the clinoid process, the dura that separates this structure from the artery is incised (Fig. 8 H). One is then in position to dissect the aneurysm base away from the ophthalmic artery, the optic nerve, and the dura of the tuberculum in aneurysms projecting superiorly and medially (Fig. 8 I), or, in aneurysms projecting inferiorly, the dura of the sella.
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and posterior clinoid, and the anterior choroidal and posterior communicating arteries, which are both usually displaced laterally. After clipping, the aneurysm is aspirated.

It is usually possible to make a judgment about the feasibility of direct clipping by the appearance of the wall of the aneurysm and its compressibility. A path for the clip must be selected that allows occlusion of the aneurysm with minimum deformity of the parent artery. It is far better to leave a portion of the aneurysm base than to encroach upon or deform the lumen of the ICA. One should select the strongest clip available for this type of lesion.

We routinely open giant aneurysms of the MCA for thromboendarterectomy before repair (Fig. 9). This is also occasionally necessary for those arising from the ICA, but is somewhat more hazardous for the following reasons: 1) the depth of the wound restricts and hinders this maneuver; 2) hemostasis is more difficult; and 3) most importantly, in those aneurysms in which this seems necessary, it has been more difficult to convert the base of the aneurysm, which is often a fusiform dilatation of the ICA, into a smooth, endothelialized vascular channel.

Posterior Circulation Aneurysms

We have employed a variety of techniques for those difficult aneurysms in the posterior circulation, with only a modest degree of success. In the future, various types of bypass grafts and profound hypothermia may play a role in the management of these cases.

Summary of Cases

Incidence of Giant Aneurysms

The incidence of aneurysms according to the five general locations used for analysis is summarized in Table 1. There were 51 giant aneurysms of the ICA; of these, nine were in the cavernous sinus, 33 were clinoidal (18 projected superiorly, 10 projected inferiorly, and five involved the entire vessel from the clinoid to its bifurcation in a fusiform), and nine were located at the bifurcation.

Effect of Subarachnoid Hemorrhage

The results of surgery according to aneurysm location with and without recent SAH (within the past 30 days) are summarized in Table 2. There were six poor results and one death in patients with a recent SAH, three of these could be ascribed to the preoperative neurological grade of the patient.

Operation and Aneurysm Location

The results of surgery for ICA and MCA aneurysms, according to the type of operation used, are summarized in Tables 3 and 4. The diversity of our approaches, the generally disappointing results achieved, and the relatively small number of cases make tabular analysis of BAC and VB cases difficult to evaluate. However, these cases are summarized together in Table 5.

Further analyses according to location and the type of surgery in the 51 ICA cases are summarized in Table 3: 1) cavernous sinus (nine cases: three ICA ligation alone, five ICA ligation plus STA-MCA bypass, and one trapping); 2) clinoid (33 cases: one common carotid artery (CCA) ligation, three ICA ligation alone, four ICA ligation plus STA-MCA bypass, two trappings, and 23 direct clippings); and 3) bifurcation (nine cases: one CCA ligation, two ICA ligation plus STA-MCA bypass, and six direct clippings).

Blood Flow Measurements

Six patients had only a modest change in CBF with temporary ICA ligation (49.2 ± 4.2 ml/100 gm/min baseline, 35.8 ± 4.5 ml/100 gm/min with ICA occlusion). All of these patients tolerated acute ICA ligation without complication. The three patients who tolerated trapping had comparable flows.

Ten patients had a substantial reduction in CBF with temporary ICA ligation (43.6 ± 2.9 ml/100 gm/min baseline, 22.7 ± 1.7 ml/100 gm/min with ICA occlusion). These patients underwent a staged (Selverstone clamp) ligation of the ICA in conjunction

TABLE 4

<table>
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<th>Type of Surgery</th>
<th>Results of Completed Surgery</th>
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<td>Thrombectomy with clipping</td>
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<tr>
<td>Excision with bypass</td>
<td>1  1  --  --</td>
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*MCA = middle cerebral artery.

TABLE 5

Method of treatment: giant aneurysms of basilar artery caput and vertebrobasilar trunk

<table>
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<th>Type of Surgery</th>
<th>Results of Completed Surgery</th>
</tr>
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<tr>
<td>Excision &amp; clipping</td>
<td>1  --  1*  --</td>
</tr>
<tr>
<td>Extracorporeal bypass</td>
<td>4  3  4†  1</td>
</tr>
<tr>
<td>Direct clipping</td>
<td>1†  --  --</td>
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*Later advanced to good.
†Damage to perforating vessels in three cases; major vessel occlusion in one case.
‡Patient later developed increasing neurological deficit due to enlargement of aneurysm; direct repair was accomplished elsewhere.
with an STA-MCA bypass. Nine anastomoses were proven patent by postoperative angiography; however, two of these patients were unable to tolerate ICA ligation and the Selverstone clamp had to be released. Both developed ischemic symptoms (dysphasia, hemiparesis) several hours after the clamp had been advanced to total occlusion and at a time when strong pulses were present over the site of the anastomosis. These symptoms cleared with restoration of flow. Cerebral blood flows with temporary ICA occlusion in these two individuals were 20 and 24 ml/100 gm/min.

Common carotid ligation was used in two patients in whom ICA ligation had resulted in dangerously low flows. In one patient CBF was 7 ml/100 gm/min with ICA occlusion, but 23 ml/100 gm/min with CCA ligation. He tolerated a staged CCA ligation. However, another patient with an occlusion CBF of 20 was unable to tolerate CCA ligation.

Complications

There were three poor results and one death in the patients with ICA aneurysms (see Table 2). All of these occurred among the nine cases in which the aneurysm was located at the bifurcation of the ICA. In two of these patients, the MCA was occluded by clip migration from the aneurysm onto the parent artery (hemiplegia in one case, death in one case). In one patient the aneurysm was incompletely obliterated; a rebleed produced a coma vigil state, and the patient died 9 months later. One of the poor results was caused by a preoperative hemiplegia. In one additional case involving an aneurysm at the ICA bifurcation, the clip had to be removed 3 days after surgery because of encroachment upon the lumen of the MCA at its origin from the ICA. This patient returned to her preoperative state.

As was indicated above in the section dealing with CBF measurements, it was necessary to release the ICA ligature in two cases in which ligation was not tolerated. The long-term follow-up review in one of these cases indicated a striking increase in the size of the bypass and a substantial reduction in the aneurysm size. The patency of this bypass was unexpected as usually it is necessary to have a perfusion gradient present for an anastomosis to remain open and enlarge. The other case has not been followed long enough to make a judgment regarding his progress. Both patients recovered from the deficits that led to the release of the ligations.

One patient with a CCA ligation was unable to tolerate the ligation. Her ischemic deficits largely reversed and she remains stable.

There was one death and one poor result in patients with giant aneurysms of the MCA. Both of these patients had a recent SAH, but this was unrelated to the results. In both cases the aneurysms diffusely involved the trunk and bifurcation. Attempted resection in these cases (before the era of bypass surgery) resulted in cerebral infarctions as the branches of the MCA were not preserved.

There were five poor results in BAC aneurysms. One of these patients had preoperative mental changes, but the other four did not. One of these four eventually achieved a good recovery (Case 5), and two others became functional with normal mentation but retained hemiparetic deficits. One patient remained in coma vigil. No complications could be ascribed to a recent SAH.

One patient with a giant VB aneurysm died from occlusion of her primary vertebral artery.

Discussion

Carotid Aneurysms

The cavernous sinus and bifurcation classifications are established nomenclature. Our clinoid group includes all aneurysms arising from a segment at or near the origin of the ophthalmic artery and the bifurcation of the ICA.11 If these aneurysms are approached intracranially, the clinoid process must be removed to visualize the entire aneurysm neck and this was, therefore, considered an appropriate term. Aneurysms that projected superiority were, in fact, carotid-ophthalmic aneurysms.8 Those that projected inferiorly, medially, or posteriorly did not seem to arise from a vessel wall defect near the ophthalmic artery. The fusiform aneurysms seemingly developed from ectasia of the entire vessel.

In making a determination of the feasibility of a direct approach, the location of the aneurysm and a comparison of its appearance on angiography and CT are important considerations. Cavernous sinus aneurysms cannot be approached directly without considerable risk, and this seems to be true for those at the bifurcation of the ICA (at least in our hands). Aneurysms that are much larger on CT than on angiography, which appear to have a fusiform base, or have evidence of a generous amount of thrombus formation must be considered high-risk lesions for a direct approach. The aneurysms that have projected superiority from the ICA near the origin of the ophthalmic artery have in general been amenable to direct clipping as the base has usually been pliable.

Plastic coatings, adhesives, or wrappings have not been used in any of our cases. There may be a role for this form of treatment in smaller aneurysms, but thus far we have not found a case of a giant aneurysm in which we thought it should be tried. We have on occasion reinforced the residual base of small, thin-walled aneurysms with thin cottonoid to promote scar reaction, but the aneurysms reported here have had thick walls and this has been unnecessary. We have no experience with plastics or intramural thrombosis.6,10

It has been our custom to isolate the cervical ICA in all of these cases. This gives some degree of protection if the aneurysm is explored intracranially and allows
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one to use $^{18}$Xe CBF measurements. Information from routine CBF studies in patients undergoing carotid endarterectomy has been helpful in predicting the effect of ICA ligation in patients with aneurysms. These studies have indicated that the critical CBF (the flow required to sustain a normal EEG) is 17 ml $\pm$ 1/100 gm/min. The flows required to sustain neurological function free of ischemic events are more difficult to define but appear to be in the range of 25 to 30 ml/100 gm/min. In general, our findings correspond quite closely to those of Jennett and co-workers. If occlusion CBF is above 30 ml/100 gm/min, one can predict with relative confidence that acute ICA ligation will be tolerated (particularly if supplemented with STA-MCA bypass). Flows of 20 to 30 ml/100 gm/min indicate caution as ICA ligation should be performed gradually (staged) with a Selverstone clamp. Ligation of the CCA should be evaluated for flows of 15 to 20 ml/100 gm/min with temporary ICA occlusion. Although less effective in treating the aneurysm, it has the advantage of a reduced risk with a better potential for collateral flow. Any form of ligation that produces flows below 15 ml/100 gm/min is hazardous and must be undertaken with extreme caution.

**Middle Cerebral Artery Aneurysm**

In cases of MCA aneurysms we have usually been able to open the aneurysm, complete a thrombectomy, and occlude the base with a heavy clip. During the time of MCA occlusion (a period of from 5 to 8 minutes) the mean blood pressure is raised 30 to 40 torr and the patients are given 250 mg pentobarbital intravenously. We have had no complications related to temporary MCA occlusion. One must be certain to preserve the STA in turning the scalp flap.

**Posterior Circulation Aneurysms**

We have had only modest success in the treatment of cases of PCA aneurysms. Drake has recently reviewed the problems in their treatment. This is particularly disappointing in that a relatively large share of these patients are under the age of 30 years. We have been reluctant to occlude the parent major intracranial vessel from which the aneurysm arose, but this may be the treatment of choice for some cases. It is possible that extracorporeal circulation coupled with profound hypothermia and cardiac arrest may have a role in the management of selected cases.

Some form of bypass procedure would be useful in this region to increase the tolerance toward a major vessel occlusion when this seems necessary because of the size or location, or both, of the aneurysm. However, an occipital to posterior inferior cerebellar artery (Occ-PICA) bypass will not be helpful, as these aneurysms are usually distal to the origin of the PICA. We have performed two STA to superior cerebellar artery (STA-SCA) bypass procedures for basilar occlusive disease. Both grafts were proven patent on angiography but the flows were only modest when compared to average STA-MCA or Occ-PICA flows. This was apparently related to spasm of the long segment of the STA suspended in the subarachnoid space under the temporal lobes. Nevertheless, the approach deserves further consideration as a possible modality of treatment in the future.

**Analysis of Complications**

Ischemic complications in these patients have generally occurred during the operative procedure and have been classified as immediate in type. A recent SAH has not been a major factor in determining the outcome of treatment, and no patients have developed the characteristic syndrome of delayed ischemia which is generally ascribed to vasospasm. The absence of these forms of complications can be attributed to a 10-day delay between the last SAH and surgery in this group (although this time delay is variable and shorter for small aneurysms).

The most common complications were major vessel occlusion and damage to perforating vessels. The former occurred primarily in ICA bifurcation aneurysms, the latter in BAC lesions. Both of these types of complications were related to clip migration, which in turn was produced from the disparity in tissues of the hard aneurysm and soft artery. A stronger clip is required for this type of surgery.

The relatively low morbidity from ICA ligation and combined bypass is attributable to the extensive use of intraoperative CBF monitoring. This has been an important adjunct to the procedure. Nevertheless, the amounts of flow delivered through bypass grafts vary a great deal, so even with this information one must be cautious.

Throughout the period of this report there has been a progressive decline in complications. This has, in large measure, been related to increased experience and to the use of bypass grafts for otherwise inoperable lesions.

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