We are presenting a series of 13 patients with aneurysms of the internal carotid artery (ICA), who were treated by cervical ICA ligation following the establishment of a patent extracranial-intracranial arterial bypass (EIAB). On examination by angiography or on direct exposure, all the aneurysms were deemed to be unsuitable for clipping.

Clinical Material

A summary of the clinical data in this series is given in Table 1. Four patients presented with a subarachnoid hemorrhage, and the remainder with evidence of an intracranial mass lesion. The patients were selected for ICA ligation because the neck of the aneurysm was thought to be unsuitable for safe application of a clip or ligature.

Operative Technique

The patient is anesthetized, intubated, and the head fixed in a pinion head clamp attached to a Mayfield head holder. The head is turned completely to the appropriate side, and the ipsilateral shoulder elevated 30°. The parietal branch of the superficial temporal artery (STA) is outlined by means of a Doppler ultrasound probe. The head and neck are exposed in the operative field, and an STA-middle cerebral artery (MCA) anastomosis is performed in the usual manner. The ICA is exposed, and a Selverstone clamp placed around it. An electromagnetic flow probe is placed above the Selverstone clamp. The clamp is gradually closed until the blood flow in the ICA is decreased by 50%. If there is insufficient exposure of the ICA to apply the magnetic flow meter, a needle is inserted above the Selverstone clamp, and the mean arterial pressure is measured. The clamp is closed briefly and the pressure recorded again. The clamp is then partially opened to allow the mean arterial pressure to stabilize halfway between these two values. On the 2nd or 3rd postoperative day, selective cerebral angiography is performed. The Selverstone clamp is closed completely if the anastomosis is patent.

A repeat angiogram is performed 3 months later. If the aneurysm still fills or if clinical symptoms of mass effect persist, the aneurysm is trapped and the sac decompressed (Figs. 1-3). An example of the importance of partial clamping is illustrated in the following case.

Case 10. At surgery, this patient's pCO₂ was 32 torr, and pO₂ was 108 torr, and these values remained steady during all the measurements. The mean arterial blood pressure recorded from the radial artery was 82...
Arterial bypass in giant carotid aneurysms

TABLE 1
Clinical data on 13 patients with giant carotid aneurysms*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Duration of Symptoms</th>
<th>Sex</th>
<th>Pre-Bypass Course</th>
<th>Diameter of Aneurysm (cm)</th>
<th>Aneurysm Location</th>
<th>Patent Bypass</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>63, F 2 yrs</td>
<td>75</td>
<td>paresis of VI nerve; later: exophthalmos on lt, paresis of lt III nerve</td>
<td>5</td>
<td>lt ICA</td>
<td>yes</td>
<td>improvement of lt III paresis</td>
</tr>
<tr>
<td>2</td>
<td>29, M 10 yrs</td>
<td>75</td>
<td>insufficiency of pituitary gland; later: visual field defect; bitemporal upper quadrantanopsia</td>
<td>7</td>
<td>rt ICA</td>
<td>yes</td>
<td>improvement of visual field defect</td>
</tr>
<tr>
<td>3</td>
<td>50, F 6 wks</td>
<td>75</td>
<td>SAH, in coma for 2 wks; gradual complete recovery except for III nerve palsy</td>
<td>4</td>
<td>rt ICA</td>
<td>yes</td>
<td>resolution of III nerve palsy</td>
</tr>
<tr>
<td>4</td>
<td>36, F 4 wks</td>
<td>75</td>
<td>blindness in lt eye &amp; TIA's</td>
<td>2.5</td>
<td>lt ICA</td>
<td>yes</td>
<td>no further TIA's; improvement in vision</td>
</tr>
<tr>
<td>5</td>
<td>46, F 3 mos</td>
<td>75</td>
<td>SAH, visual loss one eye, III nerve palsy; unsuccessful craniotomy for clipping of aneurysm</td>
<td>2</td>
<td>rt ICA</td>
<td>yes</td>
<td>III nerve palsy resolved; improvement of visual field</td>
</tr>
<tr>
<td>6</td>
<td>60, M 2 yrs</td>
<td>75</td>
<td>visual loss in lt eye</td>
<td>3</td>
<td>rt ICA</td>
<td>yes</td>
<td>improvement</td>
</tr>
<tr>
<td>7</td>
<td>54, F 2 mos</td>
<td>75</td>
<td>III nerve palsy &amp; severe headaches</td>
<td>3.5</td>
<td>lt ICA</td>
<td>yes</td>
<td>resolution of III nerve palsy</td>
</tr>
<tr>
<td>8</td>
<td>48, M 10 yrs</td>
<td>75</td>
<td>progressive weakness &amp; aphasia from large AVM, which was embolized; large ICA aneurysm</td>
<td>2</td>
<td>lt ICA</td>
<td>yes</td>
<td>gradual improvement in hemiparesis &amp; aphasia</td>
</tr>
<tr>
<td>9</td>
<td>36, F 3 mos</td>
<td>75</td>
<td>unsuccessful craniotomy for aneurysm clipping; TIA's, III nerve palsy, no change for 2 months</td>
<td>2.5</td>
<td>lt ICA</td>
<td>yes</td>
<td>no further TIA's; resolution of III nerve palsy within 1 week of bypass</td>
</tr>
<tr>
<td>10</td>
<td>60, F 18 yrs</td>
<td>75</td>
<td>galactorrhea, fluctuating bitemporal hemianopsia on admission, increasing frontal headaches; prolactin level only 11 ng/ml</td>
<td>3</td>
<td>rt ICA</td>
<td>yes</td>
<td>visual fields full &amp; intact; galactorrhea diminished</td>
</tr>
<tr>
<td>11</td>
<td>69, F 3 mos</td>
<td>75</td>
<td>progressive bilateral visual field deficit</td>
<td>3</td>
<td>lt ICA</td>
<td>yes</td>
<td>improvement of visual field deficit</td>
</tr>
<tr>
<td>12</td>
<td>55, F 4 mos</td>
<td>75</td>
<td>SAH, in coma for 4 wks, recovery with residual left-sided weakness</td>
<td>2</td>
<td>rt ICA</td>
<td>yes</td>
<td>complete recovery</td>
</tr>
<tr>
<td>13</td>
<td>34, M 6 wks</td>
<td>75</td>
<td>SAH</td>
<td>2</td>
<td>lt ICA</td>
<td>yes</td>
<td>recovery</td>
</tr>
</tbody>
</table>

*SAH = subarachnoid hemorrhage; TIA = transient ischemic attack; ICA = internal carotid artery.

mm Hg. The mean STA pressure, before the bypass was performed, was 48 mm Hg, considerably lower than the average recordings in our other patients. The mean pressure of the MCA branch considered for anastomosis was 69 mm Hg. The ICA was then temporarily occluded in the neck, during which time pressure in the MCA branch fell to 37 mm Hg. The anastomosis was then performed. An electromagnetic flow meter was placed around the STA branch that was anastomosed to the MCA branch. With the ICA open, the flow went from the MCA to the STA at the rate of 16 ml/min. (This was one of two cases of reverse flow in this series. In over 50 patients who received an EIAB for cerebrovascular disease, the flows were always from STA to MCA.) However, when the ICA was occluded in the neck, the flow in the bypass reversed and the flow went from the STA to the MCA at 25 ml/min. When the ICA was partially reopened such that its mean pressure was halfway between the open and closed pressure, the flow through the bypass diminished but remained at a respectable 18 ml/min. The blood flow in the ICA had been measured at 350 ml/min before manipulation. The mean pressure with the ICA open was 78 mm Hg; with the ICA closed, the pressure fell to 40 mm Hg, and the final pressure in the partially reopened ICA was 56 mm Hg.

Operative Results

The bypass was patent in all 13 patients. No patient experienced immediate or delayed ischemic com-
complications. The preoperative third nerve palsies disappeared over time, and visual acuity improved in the visually compromised patients. The mean follow-up period in this series was 18 months, with a range of 6 to 38 months. During this relatively brief period, no patient has had a subarachnoid hemorrhage or cerebral ischemic event.

Discussion

Yasargil first reported the use of EIAB for maintaining flow in an electively ligated MCA in the management of an aneurysm. Several reports have followed, further supporting this rationale. Ferguson, et al., reported good results with the use of EIAB in "giant" intracranial aneurysms. Aneurysms greater than 2.5 cm in diameter are by convention classified as "giant aneurysms." In a recent report of direct surgery on 24 patients, the mortality rate was 20.8%, and the overall morbidity (including deaths) was 37.5%. Eight of these patients had aneurysms of the ICA, of whom three died, one did poorly, and four had excellent results. Sundt and Piepgras reported a series of 74 giant aneurysms, of which 46 were located on the ICA. Of these patients, 40 had excellent results, three good, and two poor; one patient died. Seven of

FIG. 1. Upper: Preoperative cerebral angiograms, anteroposterior view (left) and lateral view (right), demonstrating a giant aneurysm. Lower: Postoperative angiogram demonstrating a patent anastomosis.
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Fig. 2. Left: Right common carotid angiogram performed 3 days after surgery. The internal carotid artery fills the aneurysm and middle cerebral artery circulation. The external carotid artery fills the anastomosis. Center: Early common carotid artery injection after the Selverstone clamp was completely closed. Right: Later arterial phase of common carotid artery injection following closure of the Selverstone clamp. Only small amounts of contrast material with very little injection pressure are used, to minimize trauma to the anastomosis.

ICA ANEURYSM UNSUITABLE FOR DIRECT OBLITERATION

STA-MCA ANASTOMOSIS SELVERSTONE APPLICATION TO ICA, CLOSURE OF SELVERSTONE CLAMP TO DECREASE FLOW BY 50% OR TO MAINTAIN ICA STUMP PRESSURE HALFWAY BETWEEN OPEN AND COMPLETELY CLOSED CLAMP

3 DAYS

ANGIOGRAM

BYPASS OPEN
CLOSE SELVERSTONE CLAMP COMPLETELY

BYPASS CLOSED
REPEAT ANGIOGRAM
2 WEEKS

BYPASS OPEN
CLOSE SELVERSTONE CLAMP COMPLETELY

REDO BYPASS

3 MONTHS REPEAT ANGIOGRAM

ANEURYSM NOT VISUALIZED

ANEURYSM VISUALIZED

TRAP ANEURYSM WITH ICA OCCLUSION ABOVE ANEURYSM-DEBULK IF CLINICAL MASS AFFECT IS PRESENT

Fig. 3. Summary of plan of management for treating aneurysms of the internal carotid artery (ICA) that are unsuitable for direct clipping.
these 46 patients were treated with ICA ligation and bypass, with excellent results.

The rationale behind performing an EIAB before ICA ligation is the attempt to minimize the risk of ischemic complications. The risk of ICA ligation is considerable. Apparently, 80% of patients will tolerate acute occlusion of one carotid artery, and 20% will not. Opening the carotid artery immediately after the first sign of ischemia does not reverse all neurological deficits. Odom and Tindall reported a series of 220 patients who had undergone common carotid artery occlusion. Thirty-four of their patients developed ischemic complications, and, even though the carotid artery was opened immediately in all cases, only 12 patients made a complete recovery; five patients were disabled, and 15 died. Embolization of clot from the ICA to the MCA may be one mechanism by which reopening an already closed clamp can lead to further infarction. The incidence of permanent neurological deficit or death in their series was 9%.

Thus, the immediate risk of carotid artery ligation is considerably greater than the cumulative risk of multiple years of harboring an unruptured, untreated aneurysm. There also appears to be a long-term ischemic risk associated with an occluded carotid artery. Long-term ischemic complications in patients with an ICA ligation have not been well elucidated. In a long-term follow-up study of 35 cases reported by German and Black, of the 33 patients who left the hospital, 10 (30%) died during the follow-up period. One other patient developed hemiparesis and aphasia 25 months after ICA ligation. Thus, at least two patients, or 6%, developed late cerebral ischemic episodes.

Oldershaw and Voris reported two cases of late stroke, occurring 1 and 13 years after carotid artery occlusion. It has been demonstrated experimentally that, although carotid ligation may not cause a neurological deficit in baboons, the circulatory reserve is inadequate to meet physiological challenges. Furthermore, carotid ligation may result in chronic elevation of blood pressure with its associated risks.

It has been suggested that carotid artery ligation may increase the danger of contralateral aneurysm formation. Increased flow and blood pressure may cause this to happen. Hassler has demonstrated that carotid artery ligation in rabbits will lead to contralateral aneurysm formation. Whether the EIAB will exert any protective effect in the genesis of these complications awaits to be proven. Clearly, if an EIAB can minimize these risks, the extra effort and surgical manipulation is worthwhile.

A more theoretical but plausible advantage of having an EIAB supplying a major portion of the MCA territory ipsilateral to the occluded carotid artery is that it would decrease the amount of collateral blood flow through the circle of Willis; thus, the flow adjacent to the aneurysm would be decreased and there would be less turbulence at that site, affording further protection to the aneurysm and enhancing the chances for thrombosis of the sac. This possible advantage becomes particularly important in view of the data suggesting that common carotid artery ligation is only protective for 1 year; however, ICA ligation, as opposed to common carotid artery ligation, does appear to give better theoretical long-term protection.

We believe that partial occlusion of the ICA with a Selverstone clamp, so that the blood flow is reduced by 50% or so that the perfusion pressure is reduced to halfway between the closed and open ICA, will offer a sump effect to enhance the flow through the bypass yet protect the hemisphere from infarction. Furthermore, partial clamping allows for final assessment of the bypass 3 days after surgery to assure patency before the final ICA ligation. We know that, as long as there is a need for collateral flow even when flow demand is minimal, a technically satisfactory bypass will remain patent. The patency in all these cases following partial ICA clamping further supports this rationale. We also believe that, by providing a pressure gradient from the STA to the MCA but still maintaining flow through the ICA, we can allow the EIAB to establish itself, thus diminishing the risk of ischemia in the first 3 days when the EIAB could occlude or be in spasm. It also allows a recheck of patency of the EIAB before the final ICA ligation.

The problem of when an ICA is safe to ligate has been studied by many investigators. A test that partially predicts safety has been reported by Miller, et al. By the use of intra-arterial injection of xenon-133 to measure regional cerebral blood flow (rCBF) and by measuring ICA stump pressure, they have been able to select patients who can tolerate carotid clamping. Of their 100 patients, 72 patients were accepted for permanent carotid ligation and 28 were rejected due to an excessive drop in CBF. Of the 72 patients treated with ligation, 21% developed temporary, and 5% prolonged, cerebral ischemic deficits. Of the patients deemed unsuitable candidates by rCBF criteria, carotid artery occlusion resulted in 32% temporary, and 11% permanent, cerebral infarction. By refining their selection criteria in the last 40 patients, they have been able to decrease the rejection rate for carotid ligation to 20% of the patients, and to lower the ischemic complication in the properly selected patients to 14% temporary deficit and no permanent deficit. Although these figures are encouraging, the rCBF measurement technique is not universally available. Furthermore, patients rejected for carotid ligation appear to be the highest risk patients for rebleeding from an aneurysm.

The results of this admittedly small series suggest that whenever a carotid artery is to be ligated electrolytically, an EIAB should be considered, to decrease the immediate and possibly late ischemic complications associated with ICA occlusion.
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References


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