# Treatment of intracavernous and giant carotid aneurysms by combined internal carotid ligation and extra- to intracranial bypass

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✓ Ten patients with intracranial internal carotid artery (ICA) aneurysms were managed by combining ICA ligation with an extracranial to intracranial bypass procedure. Nine of these grafts were proven patent by angiogram. One patient was unable to return for postoperative angiograms; his graft had appeared patent on physical examination. Seven aneurysms were intracavernous, two were giant carotid-ophthalmic aneurysms, and one aneurysm was at the intracranial bifurcation of the ICA. Despite occlusion cerebral blood flow (CBF) measurements of 20 ml/100 gm/min or less in six patients, only one patient was unable to tolerate ICA ligation. Three patients developed transient aphasia, but there were no permanent neurological deficits associated with the carotid occlusion. Seven patients had improvement in pre-existing extraocular palsies or visual field defects. Others remained stable.

The combination of an extracranial to intracranial microvascular bypass procedure with ICA ligation seems to be an effective method of treatment for aneurysms near the base of the skull that cannot be obliterated by a direct intracranial approach. The addition of the bypass procedure permits ICA ligation in patients who would not otherwise have tolerated occlusion of that vessel. Intraoperative xenon CBF measurements are an important adjunct to the operation.

KEY WORDS · carotid ligation · cavernous sinus · cerebral aneurysm · extracranial intracranial bypass · STA-MCA bypass

AROTID ligation has been a useful treatment for some aneurysms unsuitable for direct intracranial clipping. In the past it has been used with reasonable success to control aneurysms of the internal carotid artery (ICA) in the cavernous sinus and carotid-ophthalmic aneurysms.<sup>6</sup> It has also been tried for some anterior communicating artery aneurysms.<sup>20</sup> Currently, using the operating microscope, most anterior communicating artery aneurysms and carotid-ophthalmic aneurysms can be obliterated by direct intracranial approach.<sup>26</sup> However, carotid ligation remains as a treatment for intracavernous aneurysms and some giant carotidophthalmic and giant bifurcation aneurysms.<sup>26</sup>

The use of cerebral blood flow (CBF) measurements and intraoperative electroencephalographic (EEG) monitoring has effectively reduced the risk of carotid endarterectomy at this institution.<sup>27</sup> We will report here the application of these techniques to patients undergoing ICA ligation in combination with an extracranial to intracranial bypass procedure. The results of this study can be used to analyze potential flows through bypass grafts performed for the treatment of occlusive cerebrovascular disease.<sup>33</sup>

#### **Clinical Material and Methods**

#### Case Material

During the period 1975 to 1978, 323 intracranial aneurysms were treated surgically by one of the two neurovascular surgical services at the Mayo Clinic (operated on by the senior surgeon or a member of the resident staff with the senior surgeon as first assistant). Ten of these patients (3% of operations) were treated with ICA ligation in combination with extracranial to intracranial bypass grafts, and these cases are the subject of this report.

Six patients had intracavernous aneurysms, one had an aneurysm arising from the intrapetrous portion of the ICA and extending into the cavernous sinus, one patient had an aneurysm arising from the bifurcation of the left ICA with a stenosis involving the origin of

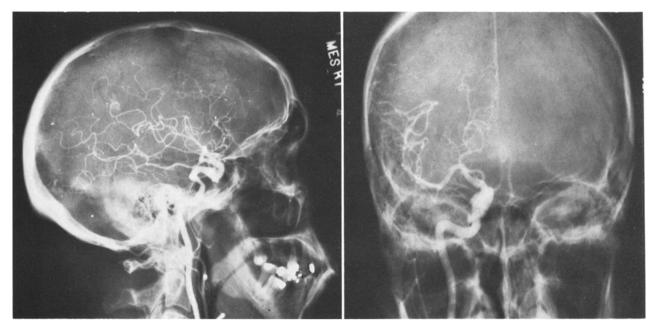


FIG. 1. Case 5. Right carotid angiogram showing a fusiform aneurysm in the cavernous portion of the right internal carotid artery. The lateral view (*left*) does not delineate it as clearly as the anteroposterior projection (*right*). Note the small  $A_1$  segment of the anterior cerebral artery suggesting minimal cross flow.

the middle cerebral artery, and two patients had giant carotid-ophthalmic aneurysms. One of the patients with a carotid-ophthalmic aneurysm had undergone an unsuccessful attempt at clipping. There were seven females and three males. Age ranged from 5 years to 60 years, with a mean of  $50.2 \pm 16.4$  years. Seven aneurysms were left-sided, three were right-sided.

# Surgical Technique

The ICA was isolated in the neck and CBF was measured by a xenon-133 (<sup>133</sup>Xe) technique before and after temporary ICA occlusion in all patients. These measurements were correlated with a continuous EEG. The neck wound was then temporarily closed, the EEG leads removed, and a single- or two-barrel superficial temporal artery to middle cerebral artery (STA-MCA) bypass procedure performed through a trephine opening. Depending upon the results of the CBF measurements, the ICA was acutely occluded using a silk ligature, or prepared for a staged ligation with a Selverstone clamp. In one patient (Case 2), this protocol was altered because of the use of a radial artery free graft.

# Monitoring Techniques

The routine for EEG and the methodology for the measurement of CBF were the same as those used for carotid endarterectomy. These have been discussed in detail previously.<sup>24,27</sup> Briefly, CBF was determined from washout curves obtained from the extracranial

detection of intra-arterially injected xenon. Cerebral blood flow was calculated from these washout curves by an automated CBF analyzer using the initial slope technique.<sup>1,21,32</sup> The 200 to 300  $\mu$ Ci of <sup>133</sup>Xe was dissolved in saline and injected into the exposed ICA through a No. 27 needle. The volume of injectate varied between 0.2 and 0.4 ml, and the amount of xenon between 200 and 300  $\mu$ Ci.

## **Case Reports**

# Case 5

This 60-year-old farmer was in excellent health until May 12, 1977, when he awoke after the sudden onset of right retro-orbital and frontal headache, followed by vomiting. Forty-eight hours later his wife noted drooping of the right upper eyelid and the patient developed diplopia.

Neurological examination at the time of hospital admission revealed a partial right third-nerve palsy. The remainder of the neurological examination was within normal limits. Over the next 4 hours the thirdnerve palsy progressed and became complete. A right carotid angiogram was performed (Fig. 1). It showed a fusiform aneurysm arising from the cavernous portion of the ICA. On July 7, 1977, a right STA-MCA bypass was performed and a Selverstone clamp placed on the right ICA. The baseline CBF was 25 ml/100 gm/min. With occlusion, this decreased to 18 ml/100 gm/min. The Selverstone clamp was gradually advanced to the point of occlusion over a 24-hour period.

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FIG. 2. Case 5. Postoperative angiogram showing nonfilling of the aneurysm and patency of the bypass graft.

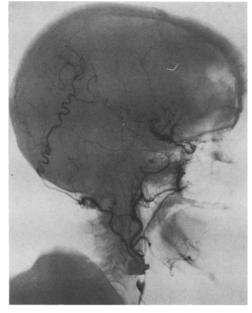


FIG. 3. Case 6. Left carotid subtraction angiogram showing nonfilling of the giant intracavernous aneurysm, patency of the left occipital to middle cerebral artery bypass, and collateral flow through the ophthalmic artery.

No new neurological deficits developed and retinal artery pressures measured after occlusion were 51/25 mm Hg on the right, and 73/51 mm Hg on the left.

Postoperative angiography (Fig. 2) showed nonfilling of the aneurysm and patency of the bypass graft. Three months postoperatively the patient's third-nerve palsy had improved and the diplopia had cleared except with extreme upward gaze.

#### Case 6

This 58-year-old woman was evaluated at the Mayo Clinic for headache and a progressive left third-nerve palsy. In 1955, she had undergone a right carotid ligation in combination with an intracranial trapping of a right intracavernous carotid aneurysm. She remained well until June, 1977, when she developed severe left retro-orbital headache and ptosis.

Examination revealed a left third-nerve palsy and a left Horner's syndrome. Angiography, performed before her arrival here, had shown an occlusion of the right ICA and a large left intracavernous aneurysm. She did not have an adequate temporal artery for an STA-MCA anastomosis and, therefore, a free radial artery graft was used to establish an anastomosis between the left external carotid artery and the anterior temporal branch of the left MCA. A Selverstone clamp was placed on the left ICA and occluded over 48 hours. Twelve hours after occlusion she developed a dysphasia which was exquisitely sensitive to position, clearing with recumbency and

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reappearing with the upright position. Angiography showed an occlusion of the radial artery graft. The hemodynamic, position-related transient ischemic attacks (TIA's) continued. Several days later, a left occipital artery to MCA bypass was performed.

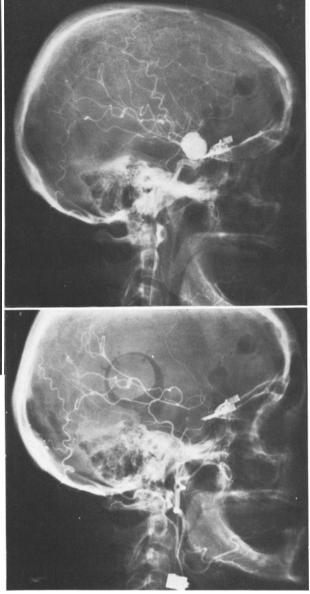
Three days after this operation, she had a single brief and transient episode of aphasia. She has had no further symptoms of cerebral ischemia over a 15month follow-up interval. Postoperative angiography (Fig. 3) was performed 1 year later by her referring physician. It showed patency of the anastomosis, nonfilling of the aneurysm, and considerable collateral circulation through the external carotid-ophthalmic artery route.

#### Case 8

This 50-year-old woman was evaluated for a progressive visual loss in the left eye. Visual field examination revealed a large central scotoma involving the left eye, and compatible with compression of the left optic nerve. A giant left ICA aneurysm arising near the origin of the ophthalmic artery was found on angiography. On September 16, 1977, a left fronto-temporal craniotomy was performed. This exploration revealed a calcified aneurysm measuring 3 cm in diameter, with a daughter sac which was also calcified. Only a portion of the aneurysm had filled on the angiograms. A heavy Drake clip was placed across the base of the aneurysm and a second shorter heavy-duty McFadden clip was placed across the daughter sac.



FIG. 4. Case 8. Left: Submentovertex x-ray film showing the jaws of the Drake clip open 3 mm across the neck of the aneurysm. Upper Right: Left carotid angiogram showing persistent filling of the aneurysm. Lower Right: Left carotid angiogram after internal carotid artery ligation and superficial temporal-middle cerebral artery bypass. There is no filling of the aneurysm and the bypass graft is patent.

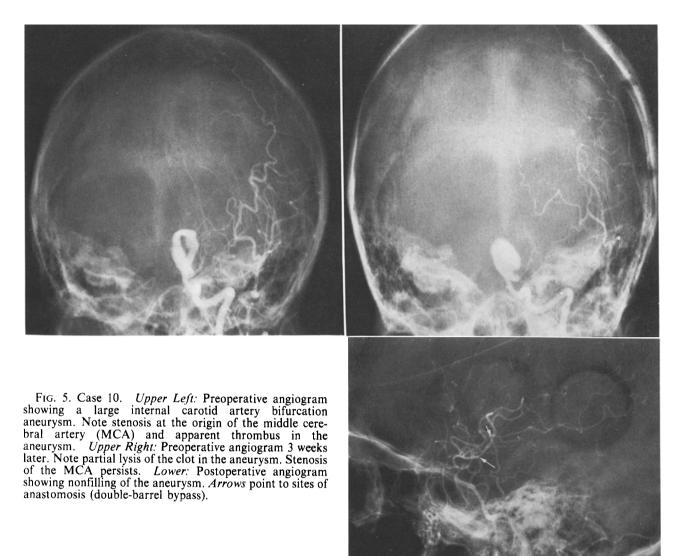


The Drake clip was reinforced with a right-angled McFadden clip placed piggyback in order to take advantage of the spring action of both clips. The aneurysm appeared to be occluded, but because of the thick walls, we could not be sure. We were hesitant to open the aneurysm because of the configuration of its base.

Postoperatively, the patient experienced subjective worsening of the vision of the left eye. Submentovertex x-ray film of the skull (Fig. 4 *left*) showed the jaws of the Drake clip open about 3 mm, and thereafter a left carotid angiogram showed that the aneurysm was still filling (Fig. 4 *upper right*). On September 30, 1977, she was returned to the operating room. The left carotid artery was exposed. Cerebral blood flow measurements demonstrated a baseline flow of 40 ml/100 gm/min. After occlusion, CBF was 15 ml/100 gm/min, a very borderline flow. A Selverstone clamp was placed on the left ICA. The previous scalp incision was reopened and an STA-MCA anastomosis completed. Care had been taken during the previous craniotomy to preserve the STA. The left ICA was occluded gradually with the Selverstone clamp over a period of 48 hours. No additional neurological deficit developed.

Postoperative angiography (Fig. 4 *lower right*) showed nonfilling of the aneurysm and patency of the bypass graft. Follow-up visual field examination, 7

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months postoperatively, revealed improvement in the central scotoma. In April, 1978, the patient underwent without incident direct clipping of a right MCA aneurysm discovered at the time of initial angiography. She has subsequently returned to full-time employment. She has normal vision in the right eye, but some persistent central field defect remains in the left.

#### Comment

This case illustrates 1) the necessity of performing postoperative angiograms on patients with giant aneurysms; 2) the difficulty in achieving occlusion at the base of some giant aneurysms; and 3) the major contribution to MCA perfusion from bypass procedures.

#### Case 10

This 54-year-old woman was admitted to the hospital with the chief complaint of left retro-orbital pain. Two weeks before admission, over a period of 18 hours, she developed a throbbing pain in the left orbit. One week before admission, because of increasing headache and confusion, she was admitted to her local hospital where a lumbar puncture disclosed xanthochromic spinal fluid. Angiograms showed a large aneurysm arising from the left ICA at the origin of the MCA (Fig. 5 upper left).

TABLE 1 Clinical findings\*

Case No.	е Туре	Sex, Age (yrs)	Nerve Palsy	Field Defect	Head- ache	SAH
1	intracavernous	F, 52	III, VI	none	yes	no
2	intracavernous	M, 5	III, IV, VI	optic nerve & chiasm	yes	no
3	intracavernous	F, 59	III, IV, V, VI	none	yes	no
4	intracavernous	F, 58	III, VI, Horner's	none	yes	no
5	intracavernous	М, 60	III	none	yes	no
6	intracavernous	F, 58	III, VI	none	no	no
7	intrapetrous, intracavernous	М, 58	VI, Horner's	none	yes	no
8	carotid- ophthalmic	F, 50	none	optic nerve	no	no
9	carotid- ophthalmic	F, 48	none	optic chiasm & tract	yes	no
10	bifurcation of ICA	F, 54	none	optic nerve & tract	yes	yes

<sup>\*</sup>ICA = internal carotid artery; SAH = subarachnoid hemorrhage.

The angiogram indicated that the blood supply to the left MCA passed through the aneurysm itself, which was either a dissecting aneurysm or an aneurysm (fusiform or berry) containing a large intraluminal clot. A marked stenosis of the MCA existed at its origin from the ICA. We believed that this aneurysm was inoperable because of the likelihood that repair of the aneurysm would effectively occlude the blood supply to the MCA.

The patient was initially managed conservatively, but, during 1 week of observation, she developed a slowly enlarging right homonymous field defect. Angiograms were repeated and demonstrated lysis of the previously identified clot in the lumen of the aneurysm (Fig. 5 *upper right*). The stenosis of the MCA persisted at its origin from the ICA. The nature of this stenosis was not clear; it could have been caused by atherosclerosis or a soft blood clot.

An occipital artery bypass procedure was attempted initially because the patient had small STA's. However, a suitable cortical recipient vessel could not be found. After an appropriate delay, two branches of the STA were anastomosed to two intracranial branches of the MCA. Simultaneously, a Selverstone clamp was placed on the ICA in the neck. The baseline CBF was 40 ml/100 gm/min, and, on occlusion, flow was 26 ml/100 gm/min. Over the next 3 days, the Selverstone clamp was advanced to occlude the vessel. The patient made an uncomplicated recovery, but retained the homonymous field defect. She was dismissed from the hospital 2 weeks after this operative procedure.

She returned to the hospital 6 months later. The neurological examination indicated a subtotal lower quadrantanopsia. Postoperative angiography (Fig. 5 *lower*) demonstrated filling of the entire MCA complex through both branches of the small STA previously anastomosed to this system. There was some dilatation in the size of the STA. The aneurysm was no longer visible.

#### Comment

This case indicates the usefulness of this procedure for bypassing inoperable giant aneurysms. The source of this patient's visual field defect could have been pressure on the chiasm, but the sharpness of the visual field abnormality without sloping margins indicated that it was probably in the optic radiation. Our provisional diagnosis was that the neurological deficit had resulted from emboli through and originating from the giant aneurysm. A deficit from spasm in association with the severe MCA stenosis could not be excluded because, at the time of the surgical procedures, blood was identified in the subarachnoid space. The preoperative angiograms had not identified a major degree of spasm.

#### Summary of Cases

#### Clinical Presentation

Table 1 summarizes the clinical findings. Extraocular palsy was present in seven patients. All of these patients had aneurysms extending into the cavernous sinus. Six patients had a third-nerve palsy, six had a sixth-nerve palsy, two had a fourth-nerve palsy, and one patient had numbness in the distribution of the first division of the fifth cranial nerve, plus dysfunction in the motor portion. One patient (Case 2), a 5-year-old boy, had a visual field defect involving the optic nerve and chiasm, presumably due to the large size of his intracavernous aneurysm. None of the other patients with intracavernous aneurysms had a visual field defect.

Two patients with carotid-ophthalmic aneurysms had visual field defects; one involved the optic nerve alone, the other involved the optic chiasm and optic tract. The patient with the large aneurysm at the bifurcation of the ICA (Case 10) had a visual field defect indicating a dysfunction of the optic nerve and optic tract. All but two patients complained of headache, rapid in onset, and retro-orbital in location. Except for Case 10, no patient had a subarachnoid hemorrhage.

#### Cerebral Blood Flow Measurements

Table 2 shows the baseline and the occlusion CBF. Four patients had regional flows of 18 ml/100

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Regional cerebral blood flow				
Case Baseline* Occlusion† No. (ml/100 gm/min) (ml/100 gm/min)				
1	57	30		
2	28	20		
3	45	18		
4				
5	21	18		
6	36	20		
7	40	18		
8	40	15		
9	60	30		
10	40	26		

TABLE 2

*Mean baseline flow = $40.78 \pm 12.40 \text{ ml}/100 \text{ gm/min}$ .
$\pm M_{\text{pop}}$ applying $\theta_{\text{pop}}$ $21.67 \pm 5.56 \text{ m}^{1}/100$ and $/\text{m}^{2}$
$\dagger$ Mean occlusion flow = 21.67 $\pm$ 5.56 ml/100 gm/min.

gm/min or less. In three patients, all with flows of 26 ml/100 gm/min or greater, acute ICA ligation was performed after an STA-MCA bypass was accomplished. In the other cases, a Selverstone clamp was left in the neck, the neck wound closed, and the STA-MCA bypass performed. After a satisfactory anastomosis was accomplished, the clamps were occluded over 24 to 48 hours.

# Postoperative Angiography

The results of postoperative angiography are summarized in Table 3. Postoperative angiography was performed on nine patients. One patient, the 5-yearold boy, was unable, for family financial reasons, to return for angiography. In eight patients the carotid artery was occluded. Final patency rate of the microvascular anastomosis in patients undergoing angiography was 100%. In six patients the site of the aneurysm was visualized and nonfilling of the aneurvsm demonstrated. In one patient, early in the series, intraoperative angiography did not include the area of the aneurysm, but demonstrated patency of the bypass.

# **Complications**

One patient (Case 6) had ischemic complications, despite a patent bypass graft, several hours after the Selverstone clamp had been advanced to total occlusion. The clamp was reopened and the dysphasia cleared. Two subsequent attempts with clamp occlusion met with similar results and, therefore, the Selverstone clamp was removed. This patient did not sustain a permanent neurological deficit. Three months later, postoperative angiography demonstrated patency of the bypass graft and a reduction in the size of the aneurysm.

Another patient (Case 9) was found to have recanalization of the ICA through the Selverstone clamp with continued filling of the aneurysm at the time of postoperative angiography. These angiograms

TABLE 3 Results of postoperative angiography

Case No.	Carotid Patency	Bypass Patency	Aneurysm
1	occluded	open	unknown
2	no angiogram	no angiogram	no angiogram
3	occluded	open	not filled
4	occluded	open	not filled
5	occluded	open	not filled
6	open	open	filled
7	occluded	open	not filled
8	occluded	open	not filled
9	occluded	open	clipped
10	occluded	open	not filled

demonstrated good perfusion through the bypass graft. At the time the patient returned for these postoperative angiograms it was found that there had been no improvement in the neurological deficits related to the mass effect of the aneurysm. We, therefore, decided to attempt a direct clipping or resection of this aneurysm. It was not possible to clip the aneurysm with the ICA patent, as we did not have an aneurysm clip strong enough to occlude the base of the aneurysm with flow permitted through the ICA. The ICA was therefore occluded, and the aneurysm was readily clipped at its base. This patient had one episode of transient dysphasia following surgery, which cleared in approximately 30 minutes. After surgery, signs and symptoms related to the mass effect of this aneurysm rapidly cleared, and the patient returned to full employment.

A third patient (Case 6), described in the case reports, developed multiple TIA's because of an occlusion of the radial artery bypass graft. These did not recur after flow was established through an occipital-MCA bypass procedure.

There was no permanent aphasia or hemiparesis in this series. One patient had a pulmonary embolism on the morning of surgery. The operation was performed without delay and anticoagulation therapy begun on the fifth postoperative day. She made an uneventful recovery.

# Long-Term Follow-Up Review

Table 4 summarizes the postoperative clinical course of these patients. A third-nerve palsy remained unimproved in two patients at the time of their 6month follow-up examination. Of the patients with field defects, three improved and one remained unchanged at last examination. Postoperative retinal artery pressures were measured on seven patients: the mean systolic difference between the two sides was 20 mm Hg, and the mean diastolic difference was 10 mm Hg.

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TABLE 4Postoperative deficits

Case No.	Hemiparesis	Aphasia	Extraocular Deficits	Field Defect
1	none	none	improved	no follow-up examination
2	none	none	improved	none
3	none	none	improved	none
4	none	transient	unchanged	none
5	none	none	improved	none
6	none	transient	unchanged	none
7	none	none	none	none
8	none	none	none	improved
9	none	transient	none	improved
10	none	none	none	improved

#### Discussion

#### Symptoms and Signs

Jefferson<sup>12,13</sup> described the clinical syndromes associated with intracavernous aneurysms and giant carotid-ophthalmic aneurysms. The various combinations of dysfunction in the nerves supplying the extraocular muscles and the occurrence of trigeminal neuropathy in the series reported here illustrate the cavernous sinus syndromes he described so vividly. Aneurysms arising just distal to the cavernous sinus do not produce extraocular palsies, but rather present with symptoms related to compression of the optic nerve, chiasm, or tract.<sup>12</sup>

#### Historical Notes

Carotid ligation historically has been successful in controlling the mass effects from an aneurysm and in minimizing the risk of an acute, recurrent SAH.<sup>19</sup> Theoretically, ICA ligation is more effective than common carotid artery (CCA) ligation. After thrombosis of the ICA, intracavernous aneurysms are eliminated from the circulation, and giant aneurysms distal to the cavernous sinus are better protected than they are after CCA ligation, as there is less effective development of collateral circulation. However, ICA ligation carries a higher risk than CCA ligation. In the Cooperative Study of Intracranial Aneurysms,<sup>19</sup> ischemic neurological deficits were reported in 59% of patients treated with ICA ligation, compared to 32% of patients treated with CCA ligation. In an attempt to minimize these complications, various tests of cerebral perfusion have been used. These include: the Matas test, angiography before and after carotid compression, occlusion of the artery under local anesthesia, and gradual or staged occlusion of the carotid artery with screw clamps. Odom and Tindall<sup>20</sup> reported a 15.5% rate of ischemic complications in 220 patients who underwent gradual ligation of the CCA. Gradual or staged ligation of the ICA or CCA was

also associated with less risk than abrupt ligation of these vessels in the Cooperative Study.<sup>19</sup>

#### Analysis of Results

In our patients, CBF was less than 18 ml/100 gm/min with ICA ligation in four patients, and one can be quite confident that these patients would have had an infarction without a supplemental bypass. Furthermore, two patients had a CBF of 20 ml/100 gm/min. This value, although adequate for sustaining cerebral function for short periods of time, is not adequate for normal cerebral function, nor does it give an autoregulatory reserve.<sup>25,29,30</sup> Therefore, we conclude that the expected complication rate in our group would have been approximately 60%, a value quite comparable to the 59% reported in the Cooperative Study.<sup>19</sup>

Only one patient in our group was unable to tolerate ICA ligation with a functional bypass graft. There was no postoperative mortality and no permanent postoperative morbidity in this group. One patient developed an ovarian malignancy and died approximately 18 months after operation. Of the six patients with preoperative extraocular muscle palsies, four improved. Visual fields were improved in three of the four patients with field defects before surgery. The fourth patient did not return for postoperative field evaluation. The theoretical problem of retrograde filling of the aneurysm through a patent bypass graft was not documented in this series.

## Analysis of Cerebral Blood Flow Measurements

We have determined from our group of patients undergoing carotid endarterectomy that CBF in older patients (over 70 years old) is often in the range of 30 to 40 ml/100 gm/min (at normocapnia) when the plaque is creating less than a 90% stenosis and producing symptomatology only from ulceration.<sup>24,27</sup> Endarterectomy has not effected a major increase in CBF in these patients. We have concluded, therefore, that blood flows in this range (under halothane or ethrane anesthesia) are adequate for normal, or nearly normal, neurological function. Accordingly, in patients with giant aneurysms, if the occlusion flow is above 30 ml/100 gm/min, one can predict with relative confidence that ICA ligation, particularly if supplemented with an STA-MCA bypass, will be tolerated. This is similar to the experience of Jennett, et al.<sup>14</sup> It should be noted that these CBF measurements are static measurements performed under controlled conditions in the operating room. The values, and those to be considered below, cannot be entirely extrapolated to the awake patient. They can, nevertheless, be used as relative standards for comparative purposes.

Patients undergoing endarterectomy, who have been neurologically unstable (frequent TIA's, progressing strokes, generalized cerebral ischemia, small infarct plus TIA's), have often had baseline CBF values of 20 to 25 ml/100 gm/min.<sup>27</sup> Clearly, blood flows in this range are marginal, and these patients are vulnerable to emboli and changes in perfusion pressure. Therefore, for patients with occlusion flows in this range, ICA ligation must be gradual (over 2 or 3 days) and supplemented with an STA-MCA bypass.

Blood flows of 15 to 20 ml/100 gm/min are even more marginal, and the surgeon should be very cautious about advancing the Selverstone clamp.<sup>5,24,27</sup> The tolerance to ICA ligation here will be critically dependent on the flows achieved through the bypass grafts, and ample time must be allowed for dilatation of the graft.

One should not consider any form of ligation that results in CBF measurements below 15 ml/100 gm/min. Blood flows below this level are correlated closely with major EEG abnormalities and, if prolonged, a fixed neurological deficit.<sup>5,18,24,27,29,30</sup> In such instances, measurement of flows with temporary CCA ligation might be helpful. Ligation of the CCA is less effective than ICA ligation in terms of creating aneurysmal thrombosis or removing it from the circulation, but, as indicated above, it is safer.<sup>19</sup>

Information from this study can be extrapolated to situations in which bypass procedures have been used in the treatment of occlusive vascular disease. The values for normal ICA flow reported in the literature have ranged from 150 to 370 ml/min.<sup>2,3,9,11,16,22,31</sup> Probable reasons for these discrepancies include differences in patient age, state of consciousness, and underlying vascular disease; instrumentation and techniques; and levels of PaCO<sub>2</sub>. The classic study of Kety and Schmidt<sup>15</sup> established that normal CBF approximated 50 to 55 ml/100 gm/min at normocapnia in normal patients. That portion of a cerebral hemisphere deriving its nourishment from the ICA weighs somewhere between 450 and 550 gm. Thus, in patients with a normal configuration in the circle of Willis, ICA flow should range between 250 and 275  $ml/100 \text{ gm/min} (50 \times 5 = 250, 55 \times 5 = 275).$ Following occlusion of this vessel, approximately 150 ml/100 gm/min must be obtained from collateral vessels (30 ml/100 gm/min for minimally adequate cerebral function  $(30 \times 5 = 150)$ ). In those patients reported here in whom occlusion flows varied between 15 and 20 ml/100 gm/min, a minimum of 75 ml/100 gm/min of flow was required through the bypass graft  $(15 \times 5 = 75, \text{ required flow} = 150)$ . This approximation is consistent with direct and indirect studies by other clinical investigators.4,17,28

Two patients in this group are of particular interest, and contribute information regarding the etiology of TIA's in patients with ICA occlusions. One of these patients, the individual who had an occlusion of the free radial artery graft, had TIA's which were clearly related to posture and were unquestionably of a hemodynamic origin. The other patient developed ischemic symptomatology with occlusion of the Selverstone clamp that was reversed when this clamp was opened. It seems equally clear that ischemic symptomatology in this patient was on a hemo-dynamic basis. These findings are consistent with the reports by Heilbrun, *et al.*,<sup>10</sup> Little, *et al.*,<sup>17</sup> and Schmiedek, *et al.*<sup>23</sup>

It should be noted that CBF measurements using these techniques are uniquely free of artifacts related to "look through" and Compton's scatter, as the indicator is delivered to the area predestined for ischemia, and the ICA is not occluded until counts are recorded.<sup>7,8</sup> Therefore, values reported as critical for cerebral function are indeed reliable. This is to be contrasted to studies using inhalation xenon techniques where, in spite of sophisticated instrumentation and technology, the true levels of flow reduction are not reflected, as the delivery of the indicator into the area of ischemia is obstructed from the same causes that produced a flow reduction in that region of focal ischemia. Elaborate studies by Boysen<sup>3</sup> have demonstrated a relative uniform reduction in hemispheric CBF with ICA occlusion, in contrast to the more focal changes identified with intracranial vessel occlusions. Although some degree of focal variability was demonstrated by Schmiedek, et al., 23 in their group of patients with ICA occlusion, these differences in regional flow were indeed modest when compared to the changes expected from a single major intracranial vessel occlusion. Therefore, although we employed only a single probe, in this particular setting the relative reductions in flow can be considered to have affected most regions in the distribution of the MCA to a similar degree. This is consistent with the correlative changes in the EEG.

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