David H. Segal, M.D., Chandranath Sen, M.D., Joshua B. Bederson, M.D., Peter Catalano, M.D., Michael Sacher, M.D., Aryeh L. Stollman, M.D., and Mordechai Lorberboym, M.D.

Predictive Value of Balloon Test Occlusion of the Internal Carotid Artery

Abstract—Balloon test occlusion (BTO) of the internal carotid artery (ICA) is used in conjunction with single-photon emission computed tomography (SPECT) imaging to assess the cerebrovascular collateral reserve prior to surgical manipulation of the artery. The present report reviews 56 consecutive patients with tumors or vascular lesions at the base of the skull who underwent BTO and subsequent treatment on that basis within a 3-year period. Four patients underwent carotid sacrifice, since they tolerated the BTO and had normal SPECT imaging. Postoperatively, one patient had patchy infarcts in the frontal lobe, another a middle cerebral artery territory infarction, a third had a lacunar infarct, and the fourth had an impending stroke and was treated with an emergent revascularization procedure. There were 15 patients who underwent saphenous vein bypass grafting, of these there were three graft occlusions, one of which resulted in an infarction. There were two other infarctions due to technical difficulties, one being related to the revascularization procedure. Based on these results, we suggest that passing BTO with a normal SPECT study does not necessarily indicate that the patient is immune to stroke following carotid sacrifice. Revascularization should be considered, when ICA sacrifice is deemed necessary to treat the pathologic condition adequately, to minimize the likelihood of a stroke. (*Skull Base Surgery, 5(2):97–107, 1995*)

Carotid sacrifice may be necessary in the treatment of certain vascular and neoplastic pathologic lesions at the skull base. Certain patients, however, do not tolerate ligation and have ischemic complications as a result thereof. Various methods have been used to predict a patient's tolerance to carotid ligation. Balloon test occlusion (BTO) followed by cerebral blood flow evaluation is one such method. Despite sophisticated technology involved in this assessment, there have been several reports of strokes after carotid ligation in patients who had been identified as having adequate collateral flow by preoperative BTO and cerebral blood flow study.[1,2] We are reporting the results of a group of patients who underwent BTO and single-photon emission computed tomography (SPECT) evaluation of cerebrovascular reserve and were subsequently managed on that basis.

CLINICAL MATERIAL AND METHODS

Fifty six patients underwent BTO at this institution within a 3-year period. BTO was performed after a 3 or 4 vessel arteriography when upper cervical, petrous, or intracavernous internal carotid artery (ICA) manipulation or resection was anticipated. Three patients had traumatic lesions, seven had aneurysms, and 46 had tumors. There were 26 men and 30 women, with ages ranging from 18 to 72 years, average age, 44.8 years. None of the patients had previously been diagnosed with cerebrovascular accidents or transient ischemic attacks (TIAs). Follow-up for patients undergoing surgery was 2 months to 3 years, including diagnostic studies at regular intervals. All patients had routine computed tomography at 1 week and 1

Skull Base Surgery, Volume 5, Number 2, April 1995 Departments of Neurosurgery (D.H.S., C.S., J.B.B.), Otolaryngology (P.C.), Radiology (M.S., A.L.S.), and Nuclear Medicine (M.L.) of the Mount Sinai School of Medicine of the City University of New York, New York, New York Reprint requests: Dr. Sen, Department of Neurosurgery, Box 1136, Mount Sinai Medical Center, One Gustave Levy Place, New York, N.Y. 10029

month postoperatively, as well as when it was otherwise indicated.

BALLOON TEST PROTOCOL

BTO was performed in conjunction with 3 or 4 vessel angiography during which careful attention was paid to the caliber of the anterior and posterior communicating arteries. BTO was not performed if an atheroma was detected at the carotid bifurcation. The patient was given a 5000 U bolus of heparin with subsequent activated clotting time (ACT) monitoring to obtain a range of 1.5 to 2 times control. A 5 or 6 F polyethylene double lumen catheter (Meditech, Watertown, MA) was then advanced under fluoroscopic guidance just distal to the carotid bulb and the balloon was inflated for 15 minutes. The blood pressure was recorded every 3 minutes and the patient was monitored neurologically and by electroencephalogram (EEG). If the patient remained asymptomatic after 5 minutes of balloon occlusion, 15 to 25 mCi of technetium-99m hexamethylphosphoramide (HMPAO) (Ceretec, Amersham, Amersham, England) was then injected intravenously. If the patient developed a neurologic deficit at any point during the occlusion, the balloon was deflated and the test was terminated immediately. After the balloon was deflated, the patient was taken to the nuclear medicine department for SPECT brain imaging. If a neurologic deficit occurred after the injection of the technetium-99m HMPAO, the patient was sent for SPECT imaging. The Tomomatic 564 scanner (Medimatic, Denmark), obtaining a total of 8 slices, was used until 1993. Since 1993, a dual head gamma camera (Vision T22, Summit Nuclear, Twinsburg, OH) was used. Transaxial, coronal and sagittal slices 1 pixel thick were reconstructed and displayed on a 128 × 128 matrix.

RESULTS

Outcome of Angiography

There were no complications related to the angiography or BTO in these 56 patients. Forty angiograms were available for review and were reevaluated for caliber of collaterals. Spontaneous cross-filling via the anterior communicating artery was graded poor or good based on the caliber of the vessel and degree of visualization of the contralateral anterior and middle cerebral artery territories. The posterior communicating artery ipsilateral to the side of the occlusion was graded poor, fetal, or good based on the caliber of the vessel and degree of visualization of the ipsilateral anterior and middle cerebral artery territories. Three patients had a poor anterior communicating artery and a poor posterior communicating artery, seven patients had a good anterior communicating artery and a poor posterior communicating artery, four patients had a good anterior communicating artery and a fetal posterior communicating artery, and 26 patients had a good anterior communicating artery and a good posterior communicating artery.

Of the three patients who had poor anterior communicating artery and posterior communicating artery; one developed transient neurologic deficits during the BTO, thus failing this test. Two had a relative decrease in flow in the cerebral hemisphere being tested compared with the opposite hemisphere on SPECT evaluation. Of the seven patients who had good anterior communicating artery and poor posterior communicating artery, one failed the BTO, four had a change in postocclusion SPECT, and two had a normal SPECT. Of the four who had a good anterior communicating artery and a fetal posterior communicating artery, two had a change in SPECT and two had a normal SPECT. Of the 26 patients with good anterior communicating artery and posterior communicating artery, one failed the BTO, eight had a change in SPECT, and 17 had a normal SPECT.

Outcome of Balloon Test Occlusion

Four patients developed transient neurologic deficits attributable to the ipsilateral hemisphere being tested. Three of them had abnormal flow on SPECT and the fourth did not have a SPECT study. Fifty-two patients tolerated the BTO; of these, five patients did not have a SPECT for unrelated reasons and 47 had SPECT scans. Twenty-four of these had normal SPECT studies and 23 had SPECT studies that showed flow abnormality on the side of the occlusion. Because of logistical problems and the need for a baseline SPECT to be done at least 24 hours prior to the postocclusion study, a baseline SPECT was not performed in most patients (Fig. 1).

Patients Who Failed Balloon Test Occlusion

Two of the four patients underwent carotid ligation with vein bypass grafting. One of them tolerated the procedure without complications, but the other had an infarction due to a middle cerebral artery branch occlusion at the distal anastomosis. The remaining two patients had a conservative operation preserving the ICA.

Outcome of Single Photon Emission Tomography Evaluation

Patients Who Passed Balloon Test Occlusion

Twenty-three patients had abnormal postocclusion SPECT studies, indicating a relative decrease in flow in the cerebral hemisphere being tested compared with the opposite hemisphere. Five patients in this group underwent carotid ligation and revascularization with a vein graft. One of them had a temporary hemiparesis from a temporal lobe infarct due to occlusion of the graft. The

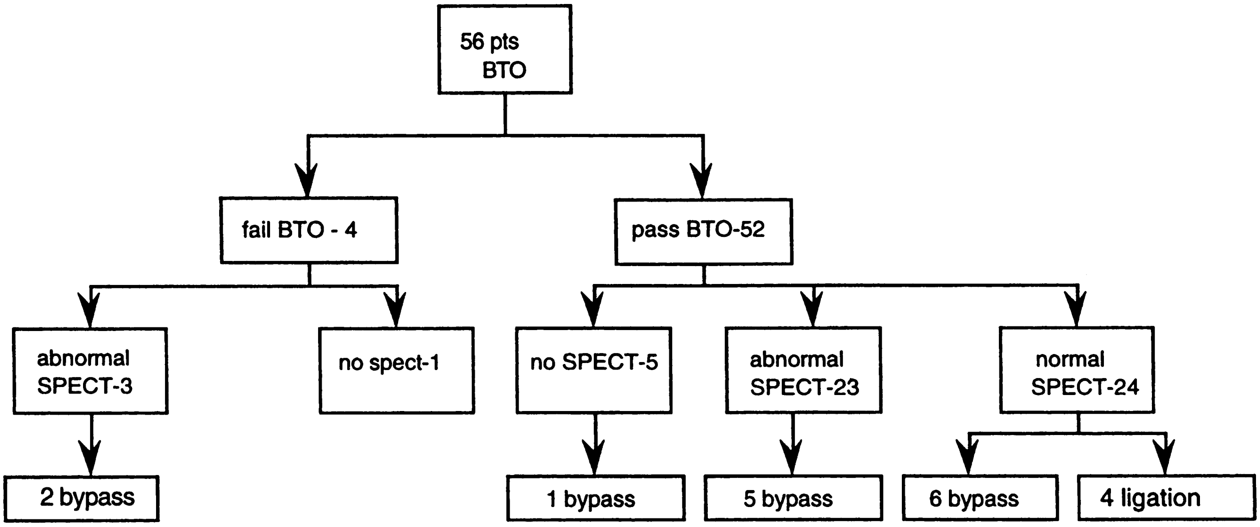


Figure 1. Results of balloon test occlusion (BTO).

remaining patients did not require resection or ligation of the artery.

In the group of 24 patients with normal SPECT, five had carotid ligation with vein bypass grafting. One of the grafts occluded without clinical consequences and the rest remained patent and normal. Four patients had carotid ligation without revascularization (Table 1) and they are described next. The remaining patients did not require resection of the vessel.

Internal Carotid Artery (ICA) Ligation Without Reconstruction

CASE 1. A 68-year-old man had a recurrent squamous cell cancer in the temporal bone involving the ICA. The ICA was ligated proximally at the bifurcation in the neck and distally, caudal to the posterior communicating artery, after which the temporal bone was resected and the defect was reconstructed with a microvascular free flap. There were no changes in the intraoperative electrophysiologic monitoring. A follow-up computed tomography (CT) scan while the patient was still in the intensive care unit on the fifth day revealed an infarct in the middle cerebral artery territory, although the patient did not have a hemiparesis (Fig. 2). Prior to this scan, the patient had to be returned to the operating room for revision of the free flap. He was lethargic and ultimately had a prolonged stay in the intensive care unit due to systemic complications.

CASE 2. This 25-year-old woman presented with a recurrent rhabdomyosarcoma in the infratemporal fossa involving the ICA. The ICA was ligated proximally in the neck and distally, caudal to the ophthalmic artery. This patient had stayed in the intensive care unit for the first 3 days after the operation with continuous monitoring. A CT scan performed a week after surgery revealed patchy infarcts in the left frontal lobe that were asymptomatic (Fig. 3). She remained well and was discharged 3 weeks after the surgery.

CASE 3. This 59-year-old woman presented with intractable left-sided facial pain and cranial nerve VI palsy due to recurrent squamous cell cancer of the skull base and cavernous sinus. The ICA was ligated proximally at the petrous segment and distally caudal to the

Table 1. Internal Carotid Artery Ligation

Patient	*Age (yr)*	*Diagnosis*	*Angiogram*	*BTO*	*SPECT*	*Site of Ligation*	*Comment*
1	68	Squamous cell carcinoma	Good AC and PC	Tolerated	No change	Caudal to PC	Right MCA infarct on CT POD 5 asymptomatic
2	25	Rhabdomyosarcoma	Good AC and PC	Tolerated	No change	Caudal to OA	Left frontal patchy infarcts, asymptomatic
3	59	Squamous cell carcinoma	Good AC and PC	Tolerated	No change	Caudal to PC	Left lacunar infarct on CT 1 month postoperative, asymptomartic
4	61	Intercavernous ICA aneurysm	Good AC and PC	Tolerated	No change	Caudal to PC	Complete hemiplegia next day after emergent ICA M_3 vein graft, no infarct on CT

AC = anterior communicating artery; PC = posterior communicating artery; OA = ophthalmic artery; M_3 = M_3 segmented middle cerebral artery.

posterior communicating artery. The postoperative course was complicated by septicemia from urosepsis. The patient developed acute onset of contralateral hemiparesis 1 month after surgery. A CT at this time showed a small infarct in the basal ganglia on the side of the ligation not seen on any previous scans (Fig. 4).

CASE 4. This 61-year-old woman presented with face pain and ophthalmoplegia due to a large right intracavernous ICA aneurysm that was mostly thrombosed. She underwent trapping of the aneurysm with ligation proximally in the neck and distally caudal to the posterior communicating artery and the thrombus in the aneurysm was evacuated. The next day she developed acute hemiplegia on her left side while seated at her bedside in the intensive care unit. She underwent emergent angiography (Fig. 5A, B) followed by revascularization with a vein graft from the cervical ICA to the M_2 segment of her right middle cerebral artery. The left hemiparesis slowly improved with no infarct seen on CT scans.

Outcome of Revascularization

Fifteen patients underwent a revascularization procedure with a vein graft. One patient did not undergo BTO due to severe carotid atherosclerotic plaques noted on angiography. Two patients failed BTO, one passed BTO

Figure 2. Case 1, a 68-year-old male with squamous cell carcinoma involving the temporal bone. Noncontrast CT scan on postoperative day 5 reveals a right middle carotid artery infarct involving the temporal lobe.

Figure 3. Case 2, a 25-year-old woman with recurrent rhabdomyosarcoma in the infratemporal fossa, involving the internal carotid artery in the petrous bone. Noncontrast CT 1 week after carotid ligation shows patchy infarcts in the lateral left frontal lobe. The patient remained asymptomatic.

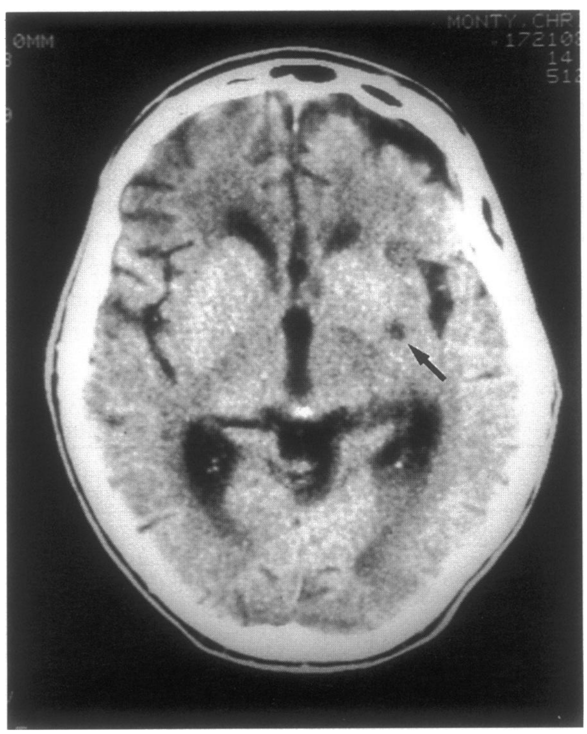
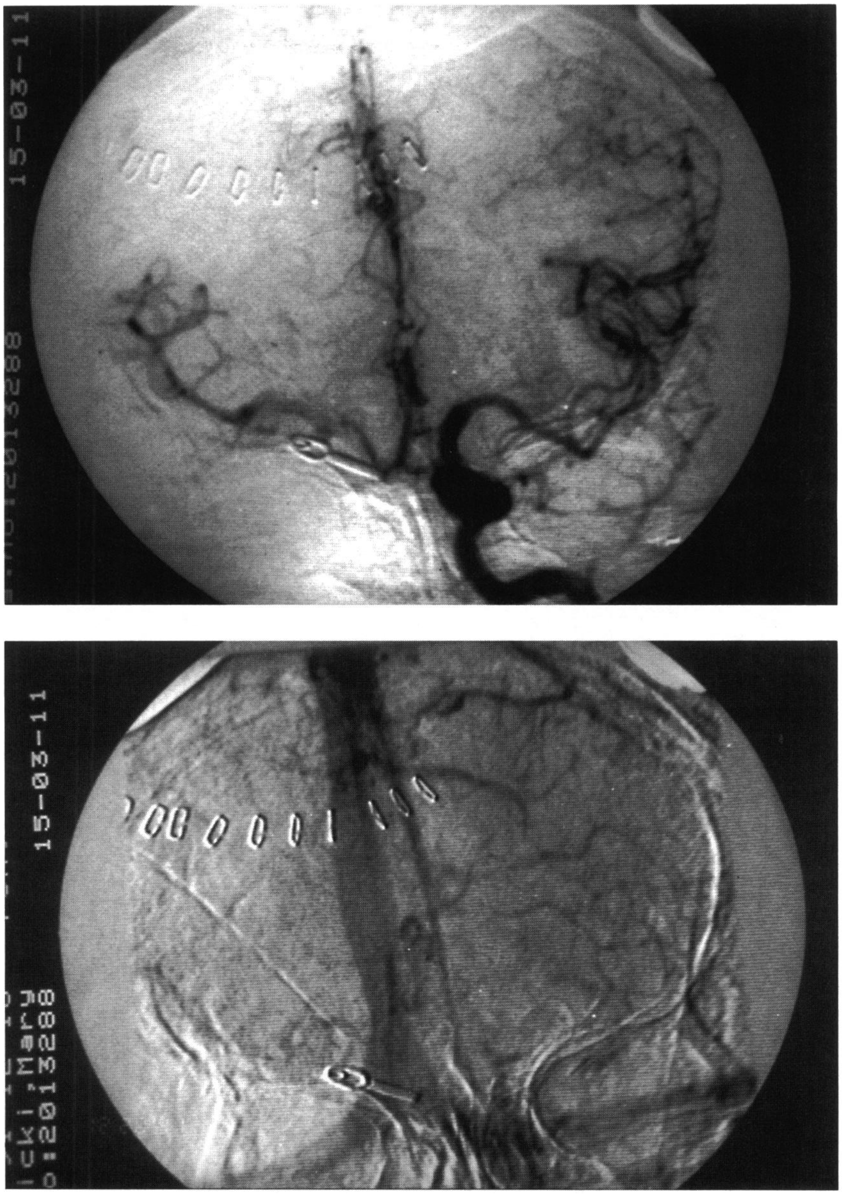


Figure 4. Case 3, a 59-year-old woman with recurrent squamous cell carcinoma of the skull base and cavernous sinus. One month following left carotid ligation, a right hemiparesis developed. Noncontrast CT at that time demonstrates left basal ganglia infarct.


A

B

Figure 5. Case 4, a 61-year-old woman with large right intracavernous internal carotid artery aneurysm. One day after ligation, she became acutely hemiplegic. A: Arterial phase of emergent postoperative angiogram shows cross-filling to right anterior cerebral and middle cerebral artery territories. However, venous phase (B) demonstrates cortical delayed filling of hemispheric veins; this may indicate hypoperfusion.

but could not have a SPECT study due to the emergent nature of his injury. Five had passed BTO but had a relative decrease in flow in the postocclusion SPECT study. Six patients (including case 4) passed the BTO with a normal SPECT and underwent revascularization.

Three of these 15 patients had infarctions from the operation: In one patient the mismatch between the vein and M_2 segment of the middle cerebral artery resulted in kinking of the distal middle cerebral artery and could have been detected if intraoperative angiography had been used. The second patient had an anterior choroidal artery distribution infarct due to a technical error in clip placement during treatment of an aneurysm and was unrelated to the bypass. The third patient had a hypercoagulable state, as documented by low serum levels of antithrombin III and proteins C and S, probably related to the malignant nature of his tumor. The vein graft repeatedly clotted despite using a fresh vein at the time of revision.

Two other patients had asymptomatic graft occlusions. They had passed their BTO and SPECT. They were done before we instituted routine intraoperative arteriography, and thus failed immediate detection.

DISCUSSION

Carotid ligation has been used for a variety of indications with a variable incidence of stroke. The first recorded case of carotid ligation was in 1778 by John Abernathy, who ligated an ICA to control hemorrhage in a patient who was gored in the neck by a cow.[3] He was successful in controlling the hemorrhage, but the patient

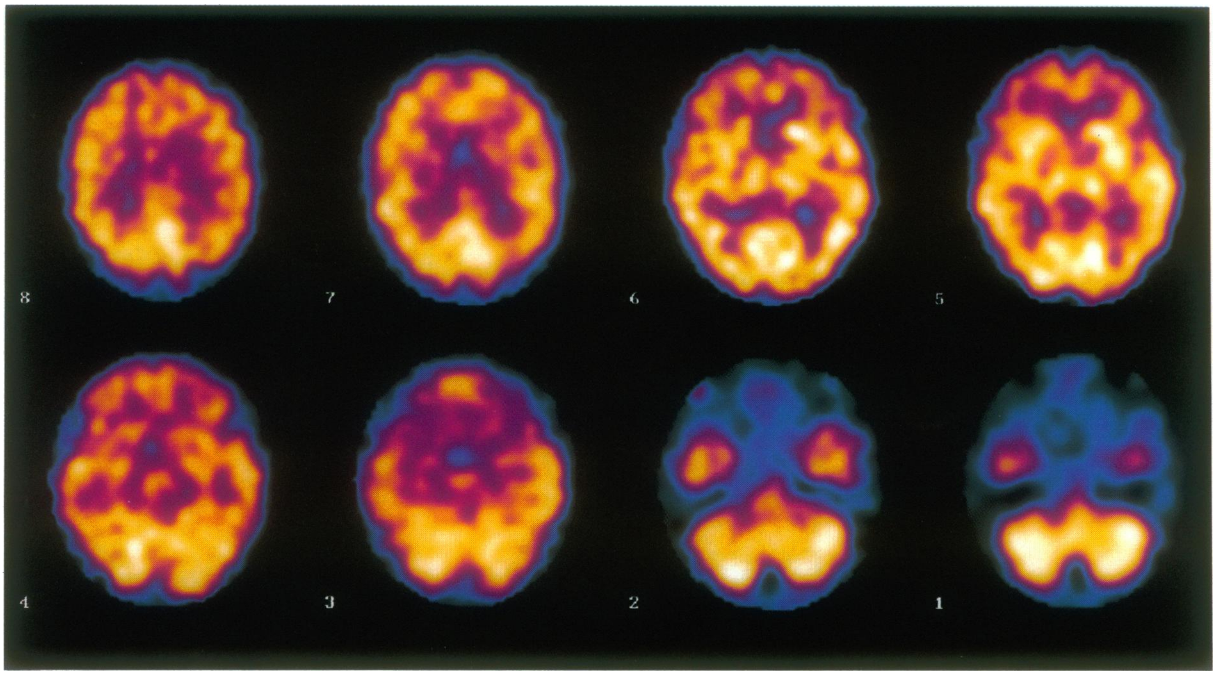


Figure 6. Transaxial slices of technetium-99m-HMPAO brain SPECT showing symmetrical perfusion to both cerebral hemispheres and the cerebellum.

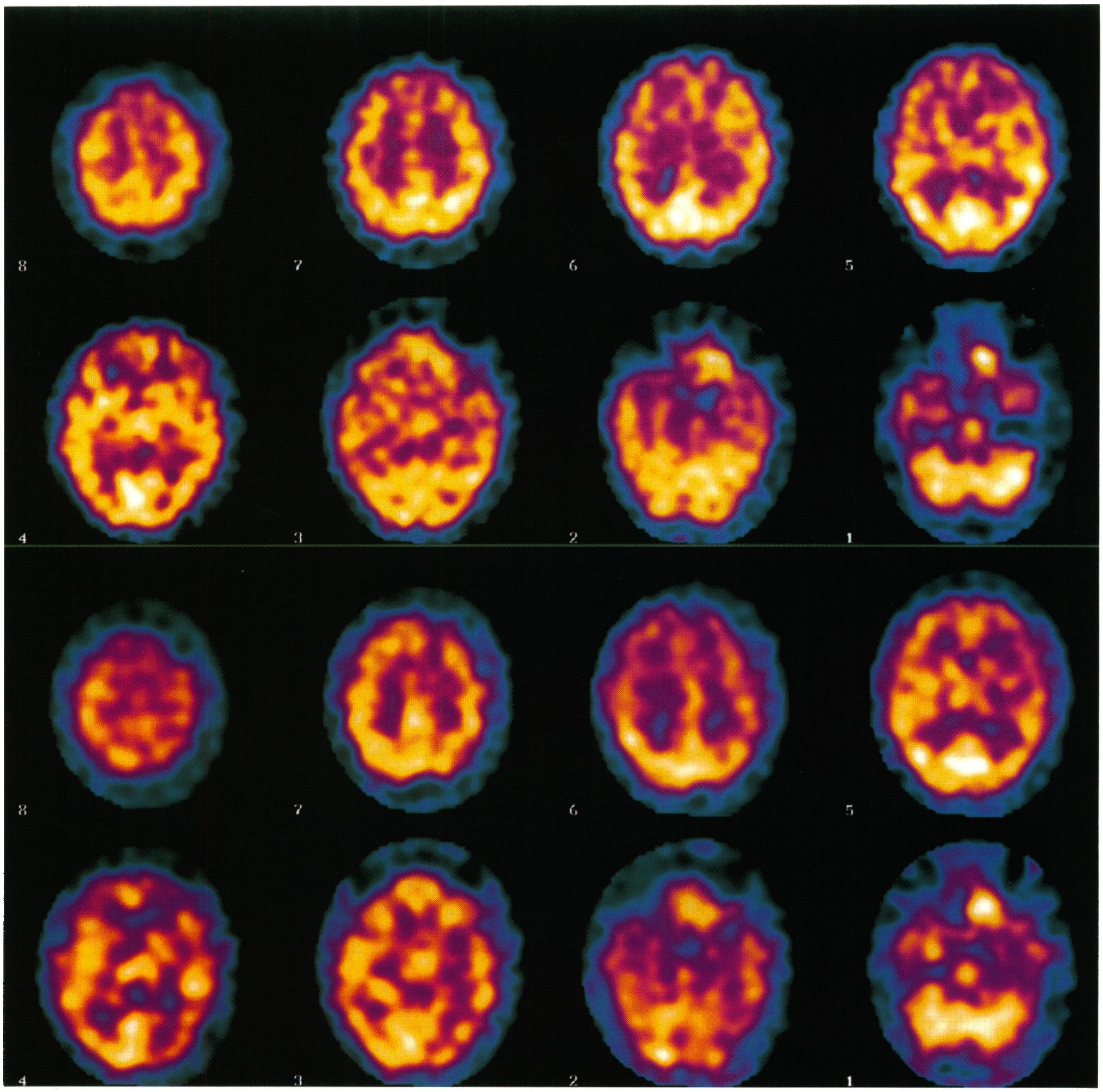
soon developed hemiplegia and died. In 1911, Rudolph Matas,[4] a general surgeon, developed a test for evaluation of collateral circulation of various organs, including the brain. He proposed controlled intraoperative test occlusion of major vessels under local anesthesia with a removable band that could be released if the patient became symptomatic. Variations of the Matas test include percutaneous carotid compression and the balloon test occlusion. In 1951 Selverstone and Crutchfeld proposed gradual occlusion of the carotid with adjustable clamps in the expectation of enhancing collateral circulation.[5] There have been conflicting reports on the benefits of gradual occlusion.[6,7] In 1966 Hiro Nishioka lead the cooperative aneurysm study in which 879 patients who underwent carotid ligation (mostly for intracranial aneurysms) were investigated.[8] Preocclusion testing was not consistent and some were high-grade subarachnoid hemorrhage. He showed an overall infarction rate of 30% as a consequence of ICA ligation; in his series the infarction rate for acute ligation was higher than for gradual occlusion.

There have been many diagnostic procedures used to detect more subtle inadequacies of collateral circulation. Most of these have proven not to be predictive of the absolute risk of infarction beyond the capacity of the Matas test. Currently, most institutions perform carotid test occlusion along with some form of cerebral blood flow measurement, such as stable xenon CT[9] and SPECT Tc-HMPAO.[10]

Tolerance of Carotid Ligation: Preoperative Testing

About 5% of patients tested fail the BTO due to poor collaterals, and anther 10 to 20% develop infarction after carotid ligation.[11,12] The Matas test has shortcomings in that it only detects the most catastrophic degree of inadequacy of collateral circulation.[13] Using provocative hypotension may significantly increase the sensitivity of the BTO and help select those patients who pass BTO but still go on to have infarctions after ligation.[14] The angiographic appearance of the collateral vessels or cross-filling has not been proven to be a reliable predictor of tolerance to carotid ligation.[15] Carotid stump pressures[9] and jugular venous saturation[16] and EEG[17] monitoring changes during BTO have not been shown to predict tolerance to carotid ligation. Transcranial Doppler is a monitoring option that provides real-time data on velocity changes in large vessels during the test occlusion.[18,19] Cerebral oximetry detects flow deficiencies prior to the onset of neurologic deterioration during the BTO.[20] Positron emission tomography in conjunction with the BTO could provide information about cerebral blood flow, oxygen extraction, and local metabolism, but is not readily available at most institutions.[21]

Both SPECT and xenon CT provide information about the cerebral blood flow during a fixed period of time. The advent of xenon CT allowed for easily repeatable quantification of cerebral blood flow during BTO.[22,23] SPECT scan uses a lipophillic tracer with extraction along the blood–brain barrier of 75%, the distribution is stable after 10 minutes and remains as such for hours.[24,25] SPECT scan provides high-resolution static images for relative flow measurements (Fig. 6). The two hemispheres are used for references with each other. A left to right difference of greater than 10% is significant for decrease in cerebral blood flow in that area[26] (Fig. 7A, B). Actually, no quantification is necessary to read perfusion brain SPECT studies. Nevertheless, quantification was performed in our cases to correlate the visual analysis with more objective data. The operators performing the quantification were blinded to the reading of the visual analysis. Six representative transaxial slices parallel to the orbitomeatal line were selected and six symmetrical pairs of regions of interest (ROIs) were placed on both sides of the brain. The ratio of the average number of counts per pixel in the lesion to the average number of counts per pixel in the contralateral nonaffected area was obtained for all patients. It is generally accepted that areas of diminished perfusion are abnormal when the interhemispheric differential activity is larger than 10%. The relative uptake in each region was normalized by the maximum cerebellar activity and compared with the corresponding ratio obtained on four normal volunteers.



A

B

Figure 7. Transaxial slices of technetium-99m-HMPAO brain SPECT. The baseline study (A) shows symmetrical perfusion to both cerebral hemispheres and the cerebellum. Images obtained immediately after technetium-99m-HMPAO was injected during balloon test occlusion of the right internal carotid artery (B) showing moderately decreased perfusion in the right frontal lobe and mildly diminished perfusion in the right temporoparietal lobe.

BTO with SPECT has certain advantages over BTO with xenon CT. SPECT study requires only one period of test occlusion, the radionuclide is injected shortly after occlusion, and it is not necessary for the patient to be transported with the catheter in place.[13] During xenon CT studies after the BTO, the patient is brought to the CT scanner without the ability to reassess the position of the endovascular catheter, the balloon is reinflated and the cerebral blood flow measurement is performed.[27] The major disadvantage of SPECT is the inability to quantitate blood flow as in xenon CT; it can only provide qualitative and semiquantative data by comparing the two hemispheres of the same study.[28] Both of these studies may be done in conjunction with an acetazolamide challenge, which leads to maximal dilation of the cerebral vasculature and renders a more sensitive assessment of cerebrovascular reserve.[22,29]

There were no complications related to the BTO in our series. The complication rate with xenon CT as an adjunct to the BTO has been quoted as 3.7%, which includes major and minor complications mostly secondary to carotid dissection.[30] All of our patients had inflation of the balloon under fluoroscopic guidance avoiding overinflation of the balloon that might cause intimal injury. This is a distinct advantage of SPECT over stable xenon CT for cerebral blood flow evaluation during the BTO.

Failure during BTO indicates grossly inadequate collaterals and higher risk of infarction even with temporary occlusion of the carotid artery.[31] Passing BTO and showing a relative decrease in cerebral perfusion on flow study indicate that the patient is at some risk of having a flow-related infarction after carotid ligation. There have been 11 reported ICA ligations on patients in such a group, 10 of these 11 had infarctions.[11] Patients who have passed the BTO with normal postocclusion cerebral blood flow on SPECT or xenon CT have undergone ICA ligation with the consideration that these results indicated a lower risk of infarction.[27] Based on our series as well as others, passing BTO with a normal postocclusion CBF study does not eliminate the risk of stroke following ICA sacrifice.[1,2]

The experience with BTO utilizing flow studies has been limited and results have varied (Table 2). deVries et al initially showed passing BTO with a normal xenon CT study is predictive of a patient's tolerance to ICA ligation. In 1990 they reported uncomplicated ligation in 22 of their 23 patients designated as low risk based on this testing.[9] Several reports of passing BTO with SPECT evaluation also showed similar results.[10,13,25,26,32] Palestro et al[33] reported a strong predictive value of the BTO with SPECT. However, a more recent study by Origitano et al[2] shows a 22% rate of infarction among patients who pass BTO with normal cerebral blood flow by SPECT. Similarly, Sekhar et al[1] had a 20% rate of infarction among patients who had previously passed BTO with normal flow by xenon CT. However, many of these patients underwent permanent balloon occlusion that may induce embolic phenomenon.

In the four cases of carotid ligation presented herein, cases 4 can be attributed to hypoperfusion. Case 1 and 2 may have been an embolic or flow-related phenomenon. The infarct in case 3 may not have been related to ICA ligation because a flow-related infarct should have occurred distally, and an embolus rarely enters a perforator vessel. Whether flow-related or embolic, a revascularization procedure may have prevented these strokes by restoring the cerebrovascular reserve, or if a saphenous vein bypass graft was used, by providing a high flow rate through the distal end of the ICA, thus reducing the risk of thrombosis and embolization. There were no significant detectable episodes of intraoperative or postoperative hypotension to account for the strokes in these four patients. Three of these patients had complications while being continuously monitored in the intensive care unit.

Our angiographic results correspond to previous studies where there was not a very strong correlation between appearance of collaterals and cerebrovascular reserve. There are too many inconsistencies based on the size of the dye bolus, the rate and force of injection, and the relationship of injection to the cardiac cycle. Most of our patients did not have a baseline SPECT study due to the technical difficulties involved in coordinating this study at least 24 hours before the postocclusion study. These patients were otherwise healthy without a history of cerebrovascular disease. The SPECT is a comparative study with the opposite hemisphere but can also be semiquantatively compared with previous studies.[28] We believe that although it is desirable to have a baseline study,

Table 2. Balloon Test Occlusion Studies

Reference	Patients	Fail BTO	Cerebral Blood Flow: Abnormal	Cerebral Blood Flow: Normal	Complications or Ligation
deVries et al[27] (xenon CT)	114	11	13	90	1/23 nomral CBF 4/5 abnormal CBF
Peterman et al[13] (SPECT)	17	0	2	15	1/5
Monsein et al[26] (SPECT)	11	0	5	6	0/2
Matthews et al[25] (SPECT)	42	8	9	25	0/13
Origitano et al[2] (SPECT and xenon CT)	100	7			4/18
Sekhar and Patel[1] (xenon CT)	39			39	8/39

the information received from the postocclusion study is sufficient in most cases for the purpose of preoperative planning, especially if the patient has no prior history of cerebrovascular disease.

Pathophysiology of Ischemia Related to Carotid Ligation

Although the cerebral vasculature responds to changes in oxygen tension, pH, and carbon dioxide tension by vasodilation and vasoconstriction, cerebral blood flow is maintained constant over a wide range of physiologic variables.[6,34,35] Ligation of one carotid artery alters this autoregulatory capacity, since the ipsilateral vascular bed undergoes some degree of vasodilation to compensate for this loss.[36,37] This renders it more sensitive to systemic hypotension and also reduces its vasodilatory response to hypoxia as shown by Sengupta et al.[37,38] This abnormal condition may last for a variable length of time.

Cerebral blood flow changes dynamically after arterial occlusion, particularly during the first 10 to 15 minutes as collaterals adapt to the reduced flow.[39] Dynamic fluctuations in cerebral blood flow after arterial occlusion such as these may account for the inaccuracy of time averaged or single determinations, such as xenon CT or SPECT.

Immediate infarction after carotid ligation is the result of reduction of cerebral blood flow below the ischemic threshold.[38,39] Delayed infarction may result either from hypoperfusion[40] or a thromboembolic complication from the ligated stump of the artery or from an intravascular balloon.[23,41] Nishioka reported that 79% of ischemic deficits after carotid ligation occurred within 48 hours, 10% in the next 48 hours, and 11% after 4 days.[8] However, successful surgical revascularization can remedy the hypoperfusion state by reconstituting the collateral reserve.[1] Thromboembolic problems can be prevented by minimizing the blind arterial stump distal to the site of ligation and by instituting anticoagulation.[23]

Complications of Revascularization Procedures

A variety of revascularization options are available, the advantages and disadvantages of which are listed in Table 3.[42–44] None of these is without risk. Graft occlusion is the most common complication, with patency rates reported from 66 to 95%.[43] Most of the causes of graft occlusion are technical and can be improved by experience and meticulous attention to detail. Intraoperative monitoring by a dedicated neurophysiologist can detect early ischemia, and intraoperative arteriography identifies anastomotic problems early so that they can be rectified before permanent damage.[1] Sen and Sekhar[43] reported on 30 vein graft reconstructions with a patency rate of 86% with a mean follow-up of 18 months. In their series, three of the four occlusions were asymptomatic and one patient had a massive infarct. Another three patients had minor strokes from the temporary ICA occlusion and two underwent successful emergent graft revision after acute graft occlusion.[43] In our series there was an 80% patency rate, with one of the three patients with graft occlusion having a major infarct. This patient had a hypercoagulable or prethrombotic state related to release of tissue plasminogen activity from his malignant tumor. This rare condition, found most commonly with adenocarcinomas, is relatively refractory to medical treatment and resection of the primary malignancy is usually the only course to relieve this problem.[45]

CONCLUSION

Failure of the BTO and decrease in cerebral blood flow on SPECT during the BTO can identify those patients at increased risk for stroke after carotid ligation. However, a normal SPECT after a successful BTO does not indicate that carotid ligation can be performed safely.

BTO still plays an important role in the evaluation of patients with lesions involving the ICA at the skull base,

Table 3. Pros and Cons of Revascularization Techniques

*Procedure**	*Advantages*	*Disadvantages*
STA-MCA bypass	95% patency No ICA flow interruption Long-term patency excellent	No immediate high-flow volume STA may be small or nonexistent from prior surgery
ECA-MCA vein graft	Immedicate high-flow volume No ICA interruption	Patency rates 50–60% in most hands Late occlusions Subject to extrinsic compression
ICA-ICA vein graft	Short graft, large to large vessel patency rate 80–90%	2-hour ICA flow interruption Anastomosis at depth Potential graft occlusion

*STA-MCA = superficial temporal artery to middle cerebral artery; ECA-MCA = external carotid artery to middle cerebral artery; ICA-ICA = internal carotid artery to internal carotid artery.

provided the complication rate is minimal. The results may help surgeons formulate the management strategy: determine how aggressively a lesion may be pursued; evaluate the risk of carotid manipulation or sacrifice; and, if so elected, determine the revascularization procedure of choice. Some form of vascular reconstruction should be considered whenever sacrifice of the ICA is deemed necessary, even if the patient tolerates a temporary balloon occlusion.

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REVIEWER'S COMMENTS

Sen and colleagues have described carefully collected data over a several year period that clearly document the risk of carotid ligation even when cerebral perfusion seems adequate by a static SPECT blood flow study. Clearly, their test regimen can help define patients with reduced flow with carotid ligation. Some patients fail carotid balloon test occlusion (BTO) at the outset and clearly cannot tolerate ligation. A second group of patients show some reduction in hemispheric flow on the occluded side even without neurologic deficit; these patients appear also at risk. In these two categories of patients, the surgeon generally must choose between less aggressive surgery with preservation of the patient's carotid artery or some form of bypass procedure. Although the bypass is not completely free of risk, this seemed clearly the safest way to allow for carotid resection.

Their more troubling group consisted of 24 patients who had no clinical abnormalities during BTO and had symmetrical SPECT scans, of whom four had carotid resection without reconstruction, all four of whom developed radiographic or clinical evidence of cerebral ischemia or infarction (one of these patients may have developed cerebral infarction from the primary procedure, unrelated to carotid ligation). In short, despite normal results with BTO and SPECT studies, these patients with carotid sacrifice remained uniformly at risk for cerebral infarction.

The authors discuss some of the study's limitations, including the fact that SPECT only shows relative flows. Perhaps asymmetries might have been shown in some subgroup of patients had acetazolamide been used at the time of BTO and SPECT studies. These data are not available, and the efficacy of such a test is unproven.

Given the apparent insensitivity of BTO with SPECT studies, the authors conclude that revascularization should be strongly considered any time carotid resection is required, even if a preoperative BTO and SPECT evaluation are normal. The authors note that revascularization is not without complications, but believe that intraoperative angiography at the time of revascularization will help reduce those complications, and improve the outcome after carotid artery resection.

Lawrence Pitts, M.D.