Brain Blood Flow SPECT in Temporary Balloon Occlusion of Carotid and Intracerebral Arteries

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It is important to determine preoperatively which patients can tolerate permanent occlusion of a cervical internal carotid or cerebral artery when such a procedure may be necessary to treat cerebrovascular or neoplastic lesions. Here we report our experience in combining temporary intra-arterial balloon occlusion with concomitant cerebral blood flow imaging in preoperative evaluation of such patients. Forty-two patients with a variety of cerebrovascular and neoplastic lesions underwent trial balloon occlusion of an internal carotid or intracerebral artery. Eight patients developed both neurologic symptoms as well as brain perfusion defects during trial occlusion. Nine others developed only perfusion defects. The remainder were asymptomatic and had negative scans. Brain blood flow imaging during intra-arterial balloon occlusion identified 17 patients potentially at risk for developing postsurgical ischemic deficits. Treatment alternatives to acute arterial sacrifice were developed for these patients.

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It is sometimes necessary to sacrifice a carotid artery in order to treat definitively a variety of cerebrovascular and neoplastic lesions. It is important to determine preoperatively whether a patient can tolerate this sacrifice without developing neurologic deficits. Over the years, a variety of methods have been used to evaluate a patient's tolerance of temporary carotid occlusion by either manual (*1*) or clamping techniques (*2–4*). Recently, temporary occlusion of the artery, by means of a percutaneously introduced endovascular balloon catheter, has been used to evaluate the awake patient's tolerance of occlusion of a carotid or intracerebral artery (*5*). Such a catheter can be placed and inflated for a sustained period of time, usually 30–45 min. During this time, the patient remains conscious and is evaluated continuously for the development of neurologic symptoms. If such symptoms develop, the balloon can be deflated rapidly and the patient's symptoms usually quickly subside. However, some patients who tolerate such an occlusion without development of symptoms may subsequently develop neurologic deficits when the carotid artery is permanently occluded (*4,6*). In some circumstances, propagation of a thrombus from the occluded arterial segment or thromboembolism may be the cause of a delayed neurologic deficit. The latter circumstance may be completely unpredictable, but may be minimized by surgical trapping of the involved arterial segment or by systemic anticoagulation. In other cases, a late deficit may be the result of hemodynamic failure. It may be possible to identify patients with marginal perfusion reserve by performing cerebral blood flow (CBF) studies during a period of trial arterial occlusion. At our institution, we have routinely incorporated CBF studies into the balloon occlusion examination of all patients being evaluated for permanent carotid occlusion.

The purpose of this paper is to report our experience in patients with a variety of cerebrovascular and neoplastic lesions who underwent trial balloon occlusion of an internal carotid or intracerebral artery in combination with SPECT brain blood flow imaging.

METHODS

Patients

Forty-two patients (18 men and 24 women, age range, 14–80 yr) were evaluated for permanent arterial occlusion. Diagnoses included cavernous carotid aneurysm, cavernous carotid fistulae, arteriovenous fistulae, primary brain tumors and tumors of the head and neck (Table 1).

Test Procedure

Each patient underwent trial occlusion of either an internal carotid artery (n = 40) or intracerebral artery (in one case a posterior cerebral artery and in the second case a middle cerebral artery). With the patient sedated but awake, a balloon catheter was angiographically introduced into a femoral artery, brought into position in the artery of interest and inflated for 30–45 min. Patients were evaluated continuously for development of neurologic deficits. In any patient in whom a deficit developed, the balloon was quickly deflated.

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TABLE 1
Diagnoses of Patients Undergoing Trial Balloon Occlusion of a Carotid or Intracerebral Artery with SPECT Imaging

Diagnoses	No. of patients
Vascular lesions	Total = 27
Cavernous carotid aneurysm*	19
Internal carotid aneurysm	3
Cavernous carotid fistula	2
Arteriovenous fistula	2
Traumatic carotid injury	1
Neoplastic lesions	Total = 15
Squamous-cell carcinoma of head or neck	8
Meningioma	4
Schwannoma of cranial nerve V	1
Hemangiopericytoma	1
Chondroid chondroma	1

*Five patients had bilateral cavernous carotid aneurysms, one patient had other hemispheric aneurysms and one patient also had a large arteriovenous malformation.

While the balloon was inflated, each patient was injected intravenously with approximately 740 MBq (20 mCi) of ^{99m}Tc-hexamethylpropylene amine oxime (HMPAO) (Ceretec®, Amersham Corporation, Chicago, IL). In some patients, the injection was made at the time of symptom development. The remainder of the patients were injected near the end of the 30-min occlusion period. However, one symptomatic patient was actually injected following deflation of the balloon but while symptoms continued (SPECT findings are presented in Results). Following the completion of the arteriogram, patients were brought to the nuclear medicine department for SPECT scanning, on average, approximately 2 hr after injection.

In those patients with perfusion defects noted on SPECT scans, a baseline scan was performed. In six patients, this was accomplished by a dual-isotope technique as described in Mathews et al. (7), in which the patient was injected intravenously with approximately 111 MBq (3 mCi) of ^{123}I-iodoamphetamine (IMP) (Spectamine® IMP Corporation, Houston, TX) just prior to undergoing SPECT scanning. Simultaneous SPECT scans using separate energy channels set for each isotope were then acquired. In the remainder of the patients undergoing baseline scans, a second scan using either HMPAO or IMP was performed as above, usually on the day after temporary occlusion. If ^{123}I-IMP was administered, patients were pretreated with Lugol's solution to prevent thyroid uptake and scanning was begun within 30 min of ^{123}I-IMP injection.

SPECT Imaging

Patients underwent SPECT brain imaging using a rotating triple-head scanner (Toshiba GCA 9300 with Toshiba GMS55OU computer, Toshiba America Inc., Tustin, CA) with a super-high resolution fanbeam collimator. Energy resolution with this system is 9% FWHM. For dual-isotope studies, SPECT data were obtained in a 256 × 256 matrix at 4° intervals in a 120° arc for each head with 60 sec of acquisition per angle. For single-isotope studies, data were acquired in a 256 × 256 matrix at 4° intervals in an 120° arc for each head with 40 sec of acquisition per angle if ^{99m}Tc-HMPAO was used or 60 sec per angle if ^{123}I-IMP was used.

For dual-isotope studies, energy peaking for each isotope was performed by centering a 10% window around the ^{99m}Tc energy peak and slightly offsetting a 10% window at 161 keV just above the ^{123}I peak of 159 keV. Image acquisitions were made simultaneously with each energy channel open. For single-isotope studies, a 15% window was centered around the isotope of interest. Following acquisition but prior to reconstruction, the projection data were fanbeam and uniformity corrected. Images were then reconstructed by filtered backprojection after preprocessing with an eighth order Butterworth filter with a cutoff frequency of 0.11 cycles/pixel for the ^{99m}Tc-HMPAO image set and 0.09 cycles/pixel for the ^{123}I image set. A Shepp-Logan emission computed tomography filter was then applied. Images were reconstructed in the transaxial plane with a angle parallel to the orbitomeatal (OM) line. The angle was set at the time of acquisition by aligning external landmarks on the patient's head with a laser beam from the Toshiba 9300. Reconstructed images were filmed in the transaxial plane with further reconstruction of both coronal and sagittal planes made from these data. Displayed images were 4 pixels thick (approximately 7 mm in this system).

Data Analysis

Each scan was evaluated by visual inspection by three nuclear medicine experts who were "blinded" to patients' diagnoses and location of pathology. A scan was considered positive if a defect seen on the balloon study was larger than that seen on baseline. This determination was reached by consensus among the experts. If a balloon study demonstrated no defect, a baseline study was not always obtained.

RESULTS

Vascular Lesions

Of the 27 patients with vascular lesions (Table 2), 8 developed symptoms during trial balloon occlusion and demonstrated marked defects on the SPECT scans (Fig. 1). Symptoms resolved quickly following deflation of the balloon in all patients except one. This patient was later found to have had what was most likely an embolic stroke with a

TABLE 2
Summary of Treatment in Patients with Vascular Lesions Undergoing Trial Balloon Occlusion and SPECT Imaging*

		No. of patients
Positive SPECT scan		
ECIC then carotid sacrifice		3
Gradual carotid occlusion		3†
Embolization of aneurysm only, carotid spared		2
AVM surgically removed, then carotid sacrifice		1
Carotid endarterectomy, no further surgery at this time		1
Embolization of AVF		1
Patients not operated upon		3
	Total	14
Negative SPECT scan		
Permanent carotid occlusion		10
Permanent carotid occlusion, transient symptoms		1
Patients not operated upon		1
Permanent PCA occlusion with AVF resection		1
	Total	13

*All patients were asymptomatic post-treatment unless otherwise noted.
†One patient underwent both ECIC and gradual carotid occlusion.
AVF = arteriovenous fistula; PCA = posterior cerebral artery; ECIC = extracranial-intracranial bypass; CEA = carotid endarterectomy; AVM = arteriovenous malformation.

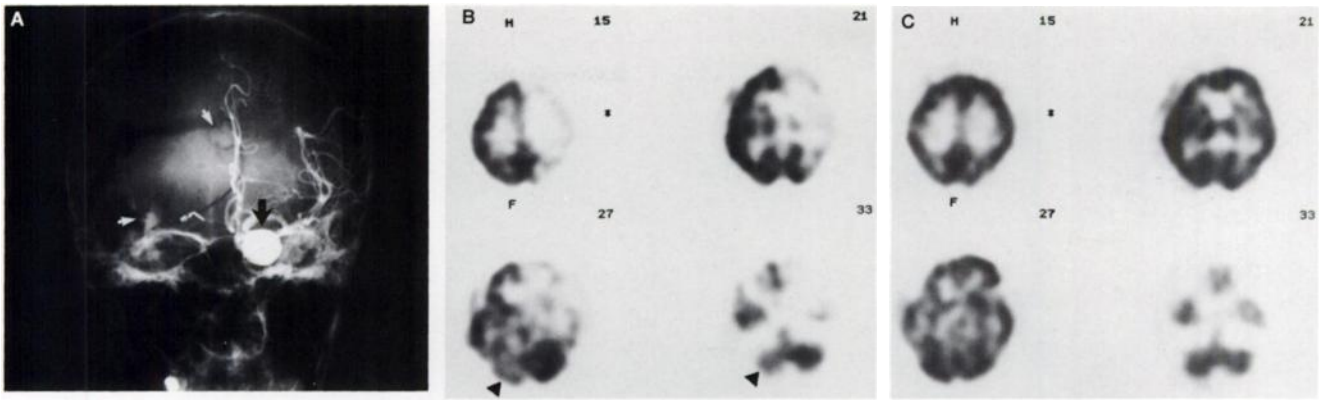

FIGURE 1. Patient with a large left cavernous carotid aneurysm. (A) Angiogram demonstrates left cavernous carotid aneurysm (black arrow). Note also the presence of previously clipped aneurysms (white arrows). (B) Representative transaxial slices of ^{99m}Tc-HMPAO SPECT scan. The patient was injected during trial balloon occlusion of the left internal carotid artery. Note the large perfusion defect involving the anterior and middle cerebral arterial distributions. Note also the crossed cerebellar diaschisis (small arrow). (C) Representative transaxial slices of the ^{99m}Tc-HMPAO SPECT scan demonstrate normal baseline perfusion.

perfusion defect in the left frontal lobe, although her neurologic deficit did ultimately resolve. In all eight patients, the treatment plan was modified based upon these findings. Three patients underwent extracranial to intracranial vascular bypass (ECIC) prior to carotid sacrifice. Two of these patients then underwent permanent occlusion of the internal carotid artery without neurologic sequelae. However, the third patient had a repeat balloon occlusion following ECIC and was still unable to tolerate carotid compromise, either clinically or based upon SPECT findings. She successfully underwent gradual occlusion of the internal cervical carotid with a Selverstone clamp and did not develop neurologic deficit when the artery was permanently ligated. One patient had his aneurysm clipped and the other had his aneurysm permanently occluded with a detachable balloon, thus leaving the carotid artery patent. A sixth patient underwent carotid endarterectomy due to presumed catheter induced embolism from a high grade plaque, but has not had further surgery. A seventh patient had no surgery and has been lost to follow-up. The patient sustaining the stroke during trial occlusion was to be reevaluated at a later time.

Nineteen patients did not develop neurologic symptoms during trial occlusion. Thirteen of these showed no significant defects on their SPECT scans. Of these thirteen, all but one have undergone uncomplicated vessel sacrifice, usually with a permanent intra-arterial balloon, and the last was not operated upon because of mitigating medical conditions.

The remaining six asymptomatic patients demonstrated positive SPECT scans even though they tolerated 30 min of occlusion. This finding modified therapy in all six patients. Two patients underwent placement of Selverstone clamps with gradual permanent occlusion of the carotid artery. One patient who had both a large arteriovenous malformation (AVM) and cavernous carotid aneurysm underwent resection of the AVM prior to carotid sacrifice. This was done to minimize a possible steal effect which might limit her tolerance of permanent carotid sacrifice. A postresection trial balloon occlusion with SPECT scan demonstrated marked improvement in the perfusion defect noted on the previous balloon scan. A fourth patient tolerated trial balloon occlusion but developed a focal neurologic deficit while undergoing a later cerebral arteriogram. She made a good recovery from this probable embolic event and subsequently, she underwent ECIC bypass because of her abnormal SPECT scan. Her carotid artery was then sacrificed without further neurologic events. A fifth patient had partial embolization of his arteriovenous fistula in preparation for future resection of the fistula. The sixth patient demonstrated a defect on balloon occlusion scan but did not have a baseline scan because he did not require further surgery.

Neoplastic Lesions

Of the fifteen patients with neoplastic lesions (Table 3), none developed neurologic symptoms during occlusion. However, three patients did demonstrate positive SPECT studies. Two of these patients required carotid sacrifice for definitive treatment of their tumors. Both patients had neurologic symptoms postoperatively. One patient developed carotid sinus instability and the other had a stroke in a watershed region which was abnormal on SPECT at the time of balloon occlusion (Fig. 2). The third patient who

TABLE 3
Summary of Treatment in Patients with Neoplastic Lesions Undergoing Trial Balloon Occlusion and SPECT Imaging

Positive SPECT Scan		N
Carotid sacrifice with neurologic deficit		2
Patients not operated upon		1
	Total	3
Negative SPECT Scan		
Carotid sacrifice not required		11
Carotid sacrifice, asymptomatic		1
	Total	12

N = number of patients.

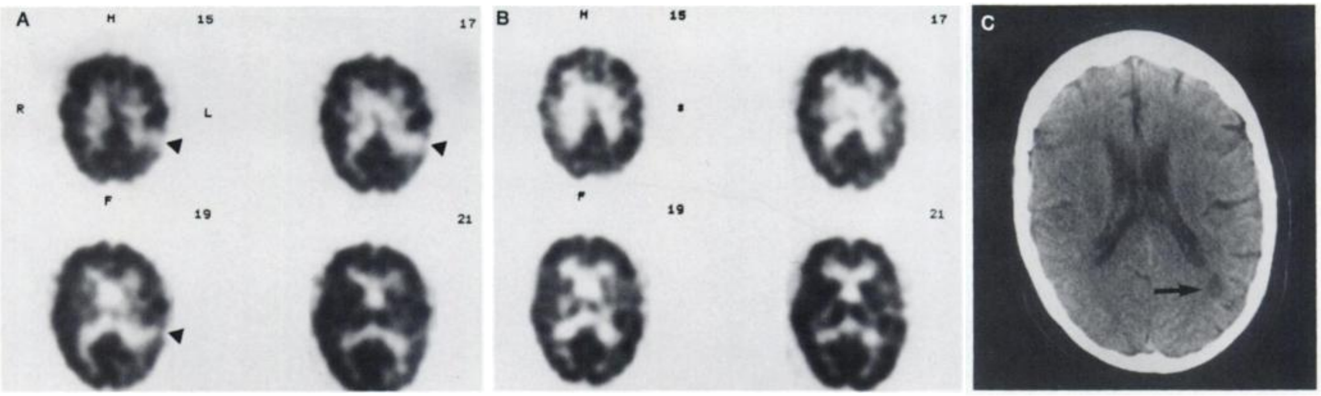

FIGURE 2. Patient with a squamous-cell carcinoma of the left neck. The carotid artery had to be sacrificed to treat the cancer. The patient subsequently had a stroke during a hypotensive episode. (A) Representative transaxial slices of ^{99m}Tc-HMPAO SPECT during trial balloon occlusion of the left internal carotid artery. Note area of decreased perfusion in the left parieto-occipital watershed distribution (arrow). (B) Representative transaxial slices of ^{99m}Tc-HMPAO SPECT demonstrate normal baseline perfusion. This scan was performed after trial balloon occlusion, indicating that the patient's stroke did not occur at the time of trial occlusion. (C) Transaxial CT scan demonstrates low density infarct (arrow) in same area with decreased perfusion during trial balloon occlusion.

underwent dual-isotope SPECT scanning has yet to be operated upon but has demonstrated a large defect in the left middle cerebral artery distribution which enlarged during trial occlusion of the left internal carotid artery (Fig. 3). The remaining 12 patients had no deficits on their occlusion scans.

DISCUSSION

In the past, tolerance of carotid artery occlusion has been evaluated by a number of techniques. Matas (*2*) described clamping of the cervical carotid with a metal band, while others have used surgical clamping or manual compression of the carotid. Monitoring techniques such as electroencephalography, measurements of carotid stump pressures and measurement of CBF (*3–4,10*) have been combined with occlusion to assess the patient's clinical status. The introduction of the intra-arterial balloon catheter allows the temporary occlusion of the artery while the patient is awake, thus allowing direct assessment of the patient's neurologic status. However, more subtle ischemic changes may not be apparent on clinical examination alone.

The results of our study demonstrate the usefulness as well as feasibility of combining high resolution SPECT CBF imaging with temporary balloon occlusion. This provides rapid, accurate localization of perfusion defects in patients who develop neurologic defects during trial occlusion as well as in patients who remain asymptomatic. In our series, nine of our patients remained asymptomatic during test arterial occlusion while demonstrating marked SPECT defects. Our experience (*8*), as well as that of others (*12–14*), suggests that these patients may be at increased risk for developing neurologic deficits following permanent carotid occlusion.

Previous investigators have reported CBF measurements incorporated into trial balloon occlusion tests. These have included injected ^{133}Xe with a global or regional CBF (*3,4*) calculated using external probes as well as the use of stable xenon computed tomography. The former technique gives only a gross localization of blood flow while the latter technique has been questioned with regard to reproducibility (*15*). Other investigators have reported using high-resolution SPECT imaging, and although the number of pa-

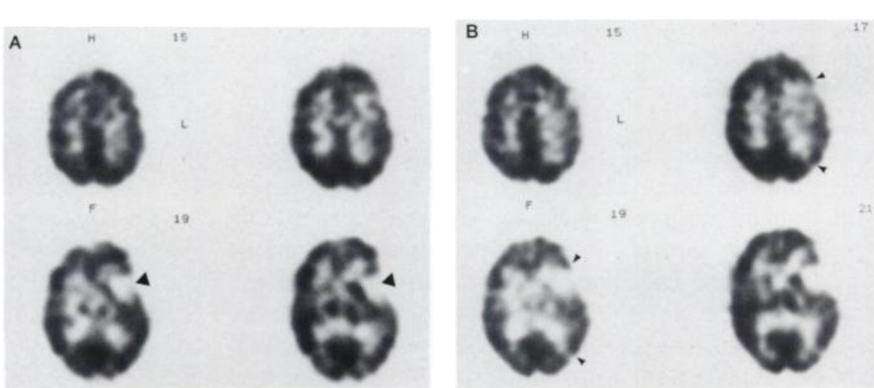

FIGURE 3. Patient with a large meningioma in the left middle cerebral artery distribution. Patient underwent dual-isotope SPECT imaging with simultaneously acquired ^{123}I-IMP and ^{99m}Tc-HMPAO scans. (A) Representative transaxial slices of ^{123}I-IMP SPECT scan demonstrate baseline perfusion. Patient was injected with isotope following trial balloon occlusion. Note the large perfusion defect on the left representing the meningioma (large arrow). (B) Representative transaxial slices of ^{99m}Tc-HMPAO SPECT scan with balloon occlusion of the left internal carotid artery. Note the large perfusion defect on the left, which now extends from the left frontal to parietal regions (small arrows), that surrounds a known area of meningioma.

tients in these studies has been small, their results parallel our own (*8,12–14*).

At our institution, SPECT data in both symptomatic and asymptomatic patients have been used not only for diagnostic purposes, but also to plan an alternative treatment strategy for the patient with perfusion defects. As reported here, four of our patients had ECIC bypass. Three of these patients were symptomatic during trial balloon occlusion and their SPECT scans were positive as well. Following bypass, two patients were able to tolerate permanent carotid occlusion without further symptoms. The third patient remained symptomatic during postbypass trial balloon occlusion and therefore underwent a gradual carotid occlusion using a Selverstone clamp. The fourth patient was bypassed because of marked abnormalities on her SPECT scan although she remained asymptomatic during trial occlusion. In addition, two other patients underwent gradual carotid occlusion based upon positive SPECT scans. While it is not certain that any of these last four patients would have had an adverse outcome without the adjunct therapy prior to permanent carotid sacrifice, we believed that abrupt permanent carotid occlusion might result in a delayed neurologic deficit.

Our data demonstrate that trial balloon occlusion with SPECT scanning is also useful in evaluating intracerebral artery occlusion. Two of our patients had large arteriovenous fistulae involving either the posterior or middle cerebral arteries. The technique worked well in each case.

In conclusion, our data suggest that SPECT scanning should be an integral part of any temporary arterial occlusion study. The data obtained may be used for diagnostic as well as therapeutic purposes. The combined technique is feasible, practical and exposes the patient to very little additional radiation.

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EDITORIAL

SPECT HMPAO and Balloon Test Occlusion: Interest in Predicting Tolerance Prior to Permanent Cerebral Artery Occlusion

For many years, the surgical treatment of an intracranial carotid artery aneurysm required the sacrifice of the internal carotid artery (ICA), even though this procedure carried with it a risk for cerebral infarction due to inadequate collateral circulation and/or thromboembolism. The physician's only choice given the diagnosis of ICA aneurysm was between surgery, with its direct and indirect risks, and simply hoping this resolved problem would remain silent. The development of interventional radiology helped assist physicians in making the decision, but until recently there was no way of accurately determining which patients possessed sufficient collateral circulation for tolerating embolization or surgery with minimal risk.

In 1911, Matas (*1*) had suggested that the manual compression of the

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