

Assessing Collateral Cerebral Perfusion with Technetium-99m-HMPAO SPECT During Temporary Internal Carotid Artery Occlusion

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Cerebral infarction following internal carotid artery occlusion results from either embolism or inadequate collateral blood flow. Although risk of embolism can be minimized, detecting compromised collateral circulation is more difficult. Cerebral angiography, carotid stump pressures and clinical evaluation during internal carotid artery occlusion are of limited utility. Xenon-133 radionuclide studies and stable xenon computed tomography are not readily available. We evaluated ^{99m}Tc -HMPAO SPECT, during temporary carotid artery occlusion, in 20 patients considered for internal carotid artery occlusion. Fourteen demonstrated symmetric cerebral perfusion during occlusion: eleven underwent transient and three had permanent carotid artery occlusion without complications. Five patients had ipsilateral globally decreased perfusion during temporary occlusion. One patient underwent transient occlusion of this vessel and one underwent carotid sacrifice without bypass grafting; both recovered without sequelae. The three remaining patients underwent carotid artery bypass grafting prior to sacrifice of this vessel. One patient with a small focal perfusion defect underwent carotid artery sacrifice without bypass grafting and developed acute neurologic deficits postoperatively. These initial results suggest that symmetric cerebral perfusion during temporary occlusion indicates that internal carotid artery occlusion will be tolerated. Although its implications are not yet well defined, the abnormal study identifies patients potentially at risk for postocclusion complications, thus providing a basis for neurosurgical management.

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A variety of neurosurgical procedures necessitate either transient intraoperative occlusion or permanent sacrifice of the internal carotid artery (ICA). The major complication of this procedure is cerebral infarction, which usually results from either embolism or hypoperfusion and ischemia due to inadequate collateral blood flow (1). Although the risk of embolism may be reduced by improved selection of the point of ICA occlusion, adjunctive heparin

administration and Doppler sonography to detect emboli in the major intracranial vessels, identification of patients with compromised collateral brain blood flow is a more difficult task. Although a variety of techniques have been evaluated, including cerebral angiography, carotid stump pressures and clinical evaluation during temporary ICA occlusion, none have proved entirely satisfactory (2-5). Recently, there have been data to suggest that cerebral blood flow imaging using ^{99m}Tc -hexamethylpropyleneamine oxime (HMPAO) SPECT may be useful in patients considered for ICA occlusion (6-9). We report the results of HMPAO SPECT performed in 20 patients during temporary balloon occlusion of the ICA.

MATERIALS AND METHODS

Patient Population

Twenty patients, 7 men and 13 women, with a mean age of 47 yr (range 17-70 yr), were included in this study. The intracranial lesions included two giant ICA aneurysms and eighteen neoplasms. All 20 individuals underwent HMPAO SPECT during temporary balloon occlusion (TBO) of the ICA, and 13 of the 20 also underwent baseline studies. All 20 patients underwent contrast cerebral angiography and clinical neurologic testing during TBO.

Examination Technique

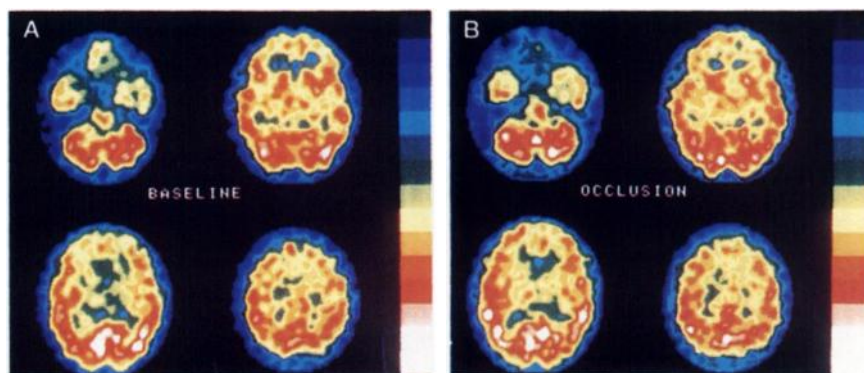
In the angiographic suite prior to TBO, the patency of the circle of Willis was evaluated by assessing the presence and caliber of the anterior and posterior communicating arteries during contrast injection into the contralateral ICA or the vertebral artery system. Following the angiographic phase of the examination, patients were given 5000-7000 units of heparin intravenously. A balloon catheter, typically a 5 French double lumen polyethylene occlusion balloon catheter (Meditech, Watertown, MA), was then advanced into the ICA up to the region of the carotid bulb. The balloon was inflated until contrast no longer flowed through the end hole. Total occlusion time was approximately 20 min, and the patient's neurologic status was continually evaluated during this time.

Technetium-99m-HMPAO was prepared from a nonradioactive kit (Ceretek, Amersham Medical, Ltd) and used within 30 min of radioligand reconstitution. Patients were injected intravenously with 15-25 mCi of tracer during TBO, which was maintained for 10 min after tracer injection. Imaging was performed following

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FIGURE 1. Images from baseline (A) and occlusion (B) HMPAO SPECT studies on a 70-yr-old woman with adenocystic carcinoma requiring sacrifice of the right ICA. There is symmetric perfusion of both cerebral hemispheres and the cerebellum on baseline images. No change in perfusion is appreciated on the images performed during TBO of the right ICA. Patient underwent right ICA sacrifice without complications. (Patient's left corresponds to viewer's left.)



balloon catheter removal and patient stabilization, usually within 30 min but not more than 2 hr after injection.

SPECT was performed on a dedicated brain imaging device (Tomomatic 564, Medimatic Corp., Denmark) equipped with a 64 NaI crystal detector system arranged in a square configuration with 16 crystals in each of four detector arrays. High-resolution collimators were employed. Energy discrimination was accomplished with a 20% window centered on the 140-keV photopeak of ^{99m}Tc . Four 10-mm thick tomographic sections were acquired simultaneously over 10 min. A total of eight slices were obtained for each study, and the total imaging time was 20 min. For those patients who underwent both baseline and occlusion studies, the time interval between the two studies was 24–72 hr. To maximize reproducibility of patient positioning, a light grid was projected onto the patient's profile, marked on the patient's skin with gentian violet and photographed.

For the purposes of analysis, images were divided into regions corresponding to the frontal, temporal, parietal and occipital lobes of the cerebrum, the basal ganglia and the cerebellum. Each of these regions on the side of ICA occlusion was visually compared with the contralateral region. When uptake in the ipsilateral and contralateral regions was equal, regional perfusion was classified as symmetric. When uptake was unequal, regional perfusion was classified as asymmetric, and ipsilateral perfusion was further categorized as increased or decreased in comparison to the contralateral side.

For the thirteen patients who underwent two radionuclide studies, baseline and occlusion images were further evaluated as to the presence or absence of alterations in perfusion between the two studies.

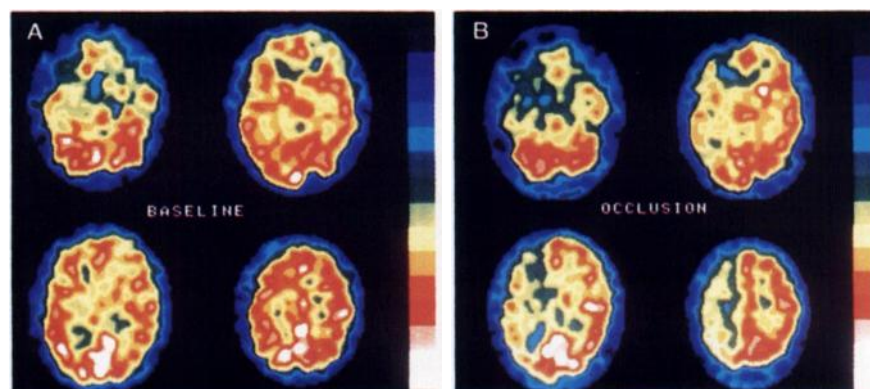
RESULTS

Patients were divided into two groups on the basis of the HMPAO SPECT results during ICA occlusion: Group A ($n = 14$) were those patients in whom cerebral perfusion was symmetric, and group B ($n = 6$) were those patients in whom cerebral perfusion was asymmetric during occlusion.

Eight of the fourteen Group A patients underwent baseline and occlusion studies. In all eight patients, regional perfusion in both studies was symmetrical. No changes in regional perfusion between baseline and occlusion studies were observed (Fig. 1). No crossed cerebellar diaschisis was noted on any of the studies in this group. All Group A patients had angiographically adequate collateral circulation, as well as normal neurologic examinations during TBO. Eleven of these patients underwent transient intraoperative ICA occlusion and none suffered any intraoperative or postoperative complications as a result of the occlusion. The remaining three patients in this group had permanent ICA occlusion and all recovered without complications.

Five of six Group B patients demonstrated uniformly decreased perfusion throughout the ipsilateral cerebral hemisphere during TBO. Four of these five patients had baseline studies, all of which demonstrated symmetric cerebral perfusion (Fig. 2). Images of the sixth patient in this group demonstrated a focal perfusion defect in the right frontal lobe, present on both baseline and occlusion stud-

FIGURE 2. HMPAO SPECT images performed on a 59-yr-old woman with a giant left ICA aneurysm. Baseline images (A) show symmetric perfusion throughout both cerebral hemispheres. Images obtained during TBO of the left ICA (B) demonstrate decreased perfusion throughout the entire left cerebral hemisphere. The patient became aphasic during TBO, and ICA bypass grafting was performed prior to sacrifice of this vessel. (Patient's left corresponds to viewer's left.)



ies. No evidence of crossed cerebellar diaschisis was observed on any of the studies. All six patients in this group had angiographically adequate collateral blood flow. Five of the six had normal neurologic evaluations during TBO. One patient, with diffusely decreased cerebral perfusion during TBO (and a normal baseline study) developed aphasia during occlusion. Among the five patients with diffusely decreased cerebral perfusion during TBO, one underwent transient operative occlusion of the ICA and suffered no complications. One patient underwent ICA sacrifice without carotid artery bypass grafting and suffered no postoperative complications. Three of the patients with ipsilateral uniformly decreased perfusion underwent carotid artery bypass grafting prior to ICA sacrifice.

The one patient in Group B whose HMPAO study demonstrated a small focal perfusion defect in the right frontal lobe, which was unchanged between baseline and occlusion studies, underwent ICA sacrifice without bypass grafting. Twenty-four hours later, she underwent emergency ICA bypass grafting because of an impending right cerebrovascular accident.

DISCUSSION

Adequate management of patients with atherosclerosis, aneurysms and tumors of the head and neck may require transient operative occlusion, or even sacrifice, of the ICA. Unfortunately, the accurate preoperative identification of individuals at risk for cerebral ischemia following ICA occlusion is an inexact science. Under normal conditions, the cerebral circulation is stable, with blood flow approximately 55 ml/100 g/min. Neuronal function is not altered until cerebral blood flow falls below 20 ml/100 g/min (10). The development of a neurologic defect during TBO of the ICA is equated with a drop in cerebral blood flow below the critical minimum of 20 ml/100 g/min and is considered irrefutable evidence that a patient will not tolerate ICA occlusion (6,10). However, the absence of neurologic dysfunction during test occlusion does not ensure that the patient can tolerate such an occlusion, and the rate of stroke following a negative TBO has been reported to range up to 20% (6). It is thought that although this technique clearly identifies individuals whose cerebral blood flow falls below the threshold for maintaining neuronal function, it fails to identify those individuals with marginal cerebral blood flow, i.e., less than 55 ml but more than 20 ml/100 g/min. Although such individuals could have a negative neurologic examination during TBO, a subsequent decrease in systemic blood pressure secondary to hypovolemia, anesthesia or sepsis could cause cerebral perfusion to fall below the critical level of 20 ml/100 g/min, resulting in cerebral ischemia or infarction (5,6,10).

There is a need therefore for a technique that can more precisely measure regional cerebral blood flow. Although cerebral angiography provides exquisite information about cerebral vasculature, this information does not reflect physiologic conditions, and consequently it is of limited

use for predicting the ability of a patient to tolerate ICA occlusion (2). Whereas carotid artery stump pressure (internal artery pressure measured distal to an occlusion) correlates with intracranial blood flow, the wide range of normal values limit its ability to identify patients with marginal cerebral blood flow (3,11). Xenon-133 radionuclide studies and stable xenon computed tomography (CT) provide quantitative data about cerebral blood flow and have improved the detection of patients at risk for cerebral ischemic events following ICA occlusion (2,5,10,11). These procedures, however, have certain limitations. The equipment required for such procedures is not readily available. Although ^{133}Xe probe measurements can be performed in the angiographic suite, only global, as opposed to regional, cerebral blood flow can be measured. If regional measurements are to be obtained with either ^{133}Xe or stable xenon CT, the patient must undergo test occlusion twice: once in the angiographic suite and a second time in the CT or nuclear imaging suite. In addition, there have been data to suggest that xenon itself may alter cerebral blood flow (12).

An alternative method of evaluating cerebral blood flow is $^{99\text{m}}\text{Tc}$ -HMPAO SPECT, which has several advantages over the xenon techniques. The tracer is available as an off-the-shelf kit and is prepared with the ubiquitous [$^{99\text{m}}\text{Tc}$]pertechnetate. Imaging can be performed with standard SPECT-capable nuclear medicine instrumentation. Equally important is that the patient need undergo balloon occlusion only once. Pharmacologic studies have shown that distribution of radioactivity in the brain is stable after the first 10 min following injection of $^{99\text{m}}\text{Tc}$ -HMPAO (13). Consequently, the patient can be injected in the angiography suite and imaged later, after the balloon catheter has been removed and the individual's condition has stabilized.

Despite the small number of patients in this series, our preliminary data suggest that HMPAO imaging can provide useful information about collateral brain blood flow in patients being considered for occlusion, either transient or permanent, of the ICA. A negative (i.e., symmetric cerebral perfusion during ICA occlusion) HMPAO study strongly suggests that an individual can tolerate at least a transient intraoperative ICA occlusion. The predictive value of a negative study, for this purpose, was 100% in our population ($n = 11$). This observation is important when viewed in light of the findings of Jawad et al. (2) who reported that 36% of patients deemed unsuitable for permanent ICA occlusion developed postoperative neurologic deficits following transient intraoperative occlusion of this vessel.

Three patients with negative HMPAO studies underwent permanent ICA occlusion, and none developed neurological deficits as a result. Although firm conclusions cannot be based on only these three patients, similar satisfactory results have been reported by others. Moody et al. (7) reported that three patients with symmetric cerebral perfusion on baseline and occlusion studies tolerated permanent ICA occlusion without any untoward sequelae. Monsein et al. (8) reported that three patients with normal

baseline and occlusion studies underwent permanent ICA occlusion without complications. In the series of Peterman et al. (6) patients with symmetric cerebral perfusion during ICA occlusion who subsequently underwent permanent ICA occlusion, of five, four recovered uneventfully. The fifth patient developed an intraoperative ipsilateral watershed infarction following aneurysm rupture with blood loss and hypotension. By combining the results reported by others with our data, the predictive value of a negative study, for a satisfactory outcome following permanent ICA occlusion, is 93% (13/14). These results are comparable to those obtained with stable xenon CT (10,11).

Although HMPAO is more sensitive than either contrast angiography or clinical evaluation for detecting alterations in cerebral perfusion following ICA occlusion, the implications of this enhanced sensitivity are yet to be determined. Three patients in our series underwent carotid artery bypass grafting based, at least in part, on an abnormal HMPAO occlusion study. Consequently, their ability (or inability) to tolerate ICA occlusion cannot be evaluated. One patient in our series with diffusely decreased perfusion on an HMPAO occlusion study, who did not undergo a bypass procedure, developed no complications following ICA sacrifice. In contrast, the patient with a small perfusion defect in the right frontal lobe, which did not change from baseline to occlusion, required an emergency revascularization procedure following development of significant neurological deficits 24 hr after ICA sacrifice. Monsein et al. (9) have observed similar variable results.

In summary, initial results indicate that HMPAO SPECT can offer important information about collateral brain blood flow in patients being considered for ICA occlusion. Symmetrical perfusion of the cerebral hemispheres during TBO strongly suggests that an individual will tolerate ICA occlusion. Although its implications are

not yet well defined, an abnormal study identifies individuals potentially at risk for post-ICA occlusion complications, thus providing a basis for neurosurgical management.

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