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.

ACKNOWLEDGMENTS

The authors thank Cathy Starnes for her assistance with preparing this manuscript. Five of the patients reported in this paper were included in a previous report by Drs. Eckard, Purdy and Bonte. In addition, a preliminary form of this report was presented at the Society of Nuclear Medicine meeting in Los Angeles, CA, June 1992.

REFERENCES

1. Toole JF, Bevilacqua JE. The carotid compression test. *Neurology* 1963; 13:601–606.
2. Matas R. Testing the efficiency of the collateral circulation as a preliminary to the occlusion of the great surgical arteries. *Ann Surg* 1911;53:1–43.
3. Leech PJ, Miller JD, Fitch W, Barker J. Cerebral blood flow, internal carotid artery pressure, and the EEG as a guide to the safety of carotid ligation. *J Neurol Neurosurg Psychiatry* 1974;37:854–862.
4. Jawad K, Miller JD, Wyper DJ, Rowan JO. Measurement of CBF and carotid artery pressure compared with cerebral angiography in assessing collateral blood supply after carotid ligation. *J Neurosurg* 1977;46:185–196.
5. Serbinenko FA. Balloon catheterization and occlusion of major cerebral vessels. *J Neurosurg* 1974;41:125–145.
6. Erba SM, Horton JA, Latchaw RE, et al. Balloon test occlusion of the internal carotid artery with stable xenon/CT cerebral blood flow imaging. *AJNR* 1988;9:533–538.
7. Mathews D, Walker BS, Allen BC, et al. Diagnostic application of simultaneously acquired dual isotope SPECT scans. *AJNR* 1993: in press.
8. Eckard DA, Purdy PD, Bonte FJ. Temporary balloon occlusion of the carotid artery combined with brain blood flow imaging as a test to predict tolerance prior to permanent carotid sacrifice. *AJNR* 1993: in press.
9. Higashida RT, Halbach VV, Dowd CF, Barnwell SL, Hieshima GB. Intracranial aneurysms: interventional neurovascular treatment with detachable balloons—results in 215 cases. *Radiology* 1991;178:663–670.
10. Matsuda H, Higashi S, Neshandar I, et al. Evaluation of cerebral collateral circulation by technetium-99m-HMPAO brain SPECT during Matas test: report of three cases. *J Nucl Med* 1988;29:1724–1729.
11. Steed DL, Webster MW, Egbert EJ, et al. Clinical observations on the effect of carotid artery occlusion on cerebral blood flow mapped by xenon computed tomography and its correlation with carotid artery back pressure. *J Vasc Surg* 1990;11:38–44.
12. Peterman SB, Taylor A, Hoffman JC. Improved detection of cerebral hypoperfusion with internal carotid balloon test occlusion and ^{99m}Tc-HMPAO cerebral perfusion SPECT imaging. *AJNR* 1991;12:1035–1041.
13. Monsein LH, Jeffery PJ, van Heerden BB, et al. Assessing adequacy of collateral circulation during balloon test occlusion of the internal carotid artery with ^{99m}Tc-HMPAO SPECT. *AJNR* 1991;12:1045–1051.
14. Moody EB, Dawson RC, Sandler MP. ^{99m}Tc-HMPAO SPECT imaging in interventional neuroradiology: validation of the balloon test occlusion. *AJNR* 1991;12:1043–1044.
15. Giller CA, Purdy P, Lindstrom WW. The effects of inhaled stable xenon on cerebral blood flow velocity. *AJNR* 1990;11:177–182.

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

Received May 5, 1993; revision accepted May 5, 1993.

For correspondence or reprints contact: Prof. S. Askienazy, Centre Hospitalier Sainte-Anne, 1, rue Cabanis, 75674 Paris Cedex, France.

carotid artery, with proper clinical monitoring, would be sufficient for determining the level of risk associated with carotid ligation for individual patients (*1*). However, the Matas test had many disadvantages. The 5-min digital compression of the carotid was too brief a period to allow collaterals to open. Efficiency of the compression was difficult to control, hence it was difficult to discriminate between insufficient compression and real tolerance. If clinical signs were evident, their significance could not be related to a loss of cerebral blood flow (CBF), slowing of regulation mechanisms or a simple reaction to the mechanical compression itself.

In this issue of the *Journal of Nuclear Medicine*, Mathews et al. (*2*) illustrate how modern techniques have dramatically enhanced the Matas approach. The use of inflatable balloons establish a more "physiologic" temporary carotid occlusion. If well tolerated, the balloon occlusion procedure can be maintained long enough (>15 min) to allow for the opening of collaterals and improvement of the hemodynamic reserve (*3*). The effectiveness of the occlusion may now be checked by angiogram. The overall permeability of the circle of Willis can be checked during the occlusion phase and, eventually, arterial pressure in the distal artery can be measured. Despite these advancements, Matthews et al. note determination of the patients' tolerance for the occlusion and prediction of the possible sequelae of the therapeutic act remains of major importance.

The typical procedure may include:

- **Angiogram.** On a sedated, heparinated patient, catheters are placed through bilateral femoral approach. The balloon is placed in the ICA at the cervical or cavernous level. An angiographic control of the occluded artery is performed. Through the second catheter, evidence for cross-filling is required as well as from the ipsilateral external carotid to see if the occlusion is real or if there is a "backfilling" from the controlateral ICA and from the vertebral arteries. An evaluation of the functional aspect of the circle of Willis can be done and of the symmetry of the two hemispheres opacification. A delay in the appearance of the veins on the occluded side is evidence of insufficient cross-filling.
- **Clinical Evaluation.** The most commonly used parameters are sensitivo-motor testing, talking, counting and loss of conciousness. Any alteration of one of these parameters should be interpreted as evidence of ischemia and should result in immediate deflation of the balloon. To predict the immediate and long-term effect of the carotid obstruction (either by ligation or embolization) is of major importance. Here are the major alternative tools and relative methods:
- **Electroencephalography.** This was the first method to evaluate brain ischemia which would result in the *apparition of focal* slowing of activity. However, its sensitivity is quite poor since major impairment of brain perfusion is necessary to induce an EEG abnormality (*4*).
- **Computed Tomography.** Stable xenon CT rCBF measurement could be of some interest (*5*) but it requires transportation of the patient with the inflated balloon already in the carotid artery. Validity of the occlusion still must be checked first when performing rCBF measurement with stable xenon. CT does not allow for many slices to be obtained. The amount of stable xenon inhaled might induce an increase in the blood velocity as shown by transcranial Doppler (*6*).
- **PET.** PET studies using ^{15}O-water allowing absolute measurements would be the only technique for evaluating the effect of ICA occlusion, but problems similar to those arising with CT remain (displacement of the patient in a different location, control of the balloon inflation, etc.).
- **SPECT.** The value of rCBF measurements during compression of the ICA has been well established since the mid seventies (*4*) when an intracarotid injection of ^{133}Xe was utilized. The availability of new brain perfusion tracers, allowing a snapshot of brain perfusion at the time of injection, which reveal little or no redistribution could change the evaluation of hemodynamic reaction to ICA occlusion. If the tracer (HMPAO) is injected during temporary occlusion of the vessel, the distribution of the radiotracer is an indicator of regional brain perfusion. With this approach, the balloon can be deflated and the catheter withdrawn. SPECT can be performed much later (after withdrawal of both catheters) as described in the study of Matthews et al. (*2*). This approach does raise some problems: Should a "baseline" study always be performed, and if so when (pre- or postballoon test)? A preocclusive SPECT study, when compared to the postocclusion study, might provide increased sensitivity for modifications of left-to-right uptake ratios (*7*). It is important to detect changes of the left-to-right ratio on homologue regions so as to discriminate between normal and altered perfusion. Monsein et al. seem to consider a 10% difference to be of high importance (*7*). Another advantage of this real "baseline" study is that it gives a real reference. If a defect is seen on a control SPECT study performed after the deflation of the balloon, it is much easier to know if the lesion was pre-existing or if it was induced by the test itself.

Another question arising from a comparison of the data in the literature is the proper timing for injection after the inflation of the balloon (when there are no clinical signs of ischemia). According to Simonson, if the tracer is injected too early, collaterals might not be completely opened and this could lead to false-positive SPECT results (*8*). The variation of the mean arterial blood pressure in the distal occluded artery clearly shows that the blood pressure never climbs above the recognized threshold of 50 mmHg, before the tenth minute post-occlusion. This shows that injection of the perfusion agent should not be done until at least 15 min postinflation. Though no clear description of the evolution after the therapeutic occlusion is given, Simonson suggests that the timing of the injection is one of the possible causes for the relatively high rate of positive SPECT results in occlusive tests. In their study, Matthews et al. keep the balloon inflated for 30–45 min, and in patients with no clinical signs the injection was performed at about the 30th minute.

We have found one patient in the literature who had ischemia following permanent occlusion despite a negative SPECT test (*9*). This might have been due to the modification of perfusion pressure during and after therapy. During the occlusion phase, the collaterals are trying to supply the occluded territory and sufficient metabolism is obtained with mobilization of the hemodynamic reserve. Some patients are probably "borderline," and a small impairment of perfusion pressure might make these patients ischemic (*10*). In order to detect these borderline patients, inducing hypotension while the balloon is inflated might be of some value. In such patients, the dual-isotope technique described by Mathews et al. might be of interest in the sense that eventual modifications of brain perfusion would be evidenced. We studied a patient who perfectly matches this description: 1 min after digital compression was begun, she started to complain of left hand hemiparesis. A few days after a balloon occlusion test was performed and during the 30 min of occlusion, no clinical signs were seen. The major difference between the two phases was blood pressure that was 2 mmHg higher during the balloon occlusion test than during the digital compression.

Another problem discussed by Mathews was the eventual modification in the therapeutic approach that should result when the SPECT test is positive. An attempt to increase collateral perfusion through ECIC bypass might be a reasonable therapeutic alternative (*9*) if another SPECT test control confirms efficient cross-filling.

There remains the problem of patients with a positive occlusion test (either clinically or scintigraphically), who tolerate slow therapeutic occlusion, usually with the Selverstone clamp or with coils. In these patients, it seems likely that a gradual occlusion of the vessel allows time for collaterals to open and become functional.

Mathews et al. conclude that brain perfusion "SPECT scanning should be an integral part of any temporary arterial occlusion study." We agree, but point out that quantification of the perfusion study is still needed to standardize the results. The influence of a positive test on the therapeutic approach is clear. Whether it should lead to systematic ECIC bypass prior to carotid sacrifice or to other embolizing techniques (coils, Selverstone clamps, etc.) is another problem. It remains that thromboembolic risk may persist, even with systematic heparinization of the patient.

Serge Askienazy
Rachida Lebtahi
Jean-Francois Meder
Sainte Anne Hospital
Paris, France

REFERENCES

1. Matas R. Testing the efficiency of the collateral circulation as a preliminary to the occlusion of the great surgical arteries. *Ann Surg* 1911;53:1–43.
2. Mathews D, Walker BS, Purdy PD, et al. Brain blood flow SPECT in temporary balloon occlusion of carotid and intracerebral arteries. *J Nucl Med* 1993;34:1239–1243.
3. Lebtahi R, Meder JF, Gaston A, De Kerviler E, Habert MO, Hardy S, Chodkiewicz JP, Askienazy S. Test d'occlusion par ballonnets et tomographie d'émission monophotonique (SPECT) au HMPAO. *J Med Nucl Biophy* 1992;16:64–67.
4. Leech PJ, Miller JD, Fitch W, Baker J. Cerebral blood flow, internal carotid artery pressure, and the EEG as a guide to the safety of carotid ligation. *J Neurol Neurosurg Psychiatry* 1974; 37:854–862.
5. Erba SM, Horton JA, Latchaw RE, et al. Balloon test occlusion of the internal carotid artery with stable xenon/CT cerebral blood flow imaging. *AJNR* 1988;9:533–538.
6. Giller CA, Purdy P, Lindstrom WW. The effects of inhaled stable xenon on cerebral blood flow velocity. *AJNR* 1990;11:177–182.
7. Monsein LH, Jeffery PJ, van Heerden BB, et al. Assessing adequacy of collateral circulation during balloon test occlusion of the internal carotid artery with ^{99M}Tc-HMPAO SPECT. *AJNR* 1991;12:1045–1051.
8. Simonson TM, Ryals TJ, Yuh WTC, Farrar GP, Rezai K, Hoffman HT. MR imaging and HMPAO scintigraphy in conjunction with balloon test occlusion: value in predicting sequelae after permanent carotid occlusion. *AJR* 1992;159: 1063–1068.
9. Eckard DA, Purdy PD, Bonte FJ. Temporary balloon occlusion of the carotid artery combined with brain flood flow imaging as a test to predict tolerance prior to permanent carotid sacrifice. *AJNR* 1992;13:1565–1569.
10. Peterman SB, Taylor A, Hoffman JC. Improved detection of cerebral hypoperfusion with internal carotid balloon test occlusion and ^{99M}Tc-HMPAO cerebral perfusion SPECT imaging. *AJNR* 1991;12:1035–1041.