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A Provocative Internal Carotid Artery Balloon Occlusion Test with ^{99m}Tc-HM-PAO CBF Mapping

—Report of Three Cases—

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Abstract

The balloon occlusion test (BOT) of the internal carotid artery (ICA), combined with induced hypotension and cerebral blood flow (CBF) mapping, was carried out in three patients with a large or giant aneurysm of the ICA. Occlusion of the ICA for 10 minutes in the normotensive state was followed by 5 minutes of induced hypotension. During the last 2 minutes of hypotensive occlusion, technetium-99m-hexamethyl-propyleneamine oxime was administered to study the CBF. All patients tolerated the procedure well. One patient with moderate CBF reduction developed ischemic complications 24 hours after permanent ICA occlusion. Another showed no significant change in CBF and tolerated permanent ICA occlusion well, while the third refused permanent occlusion. The provocative BOT combined with CBF mapping is a promising predictor of complications of ICA occlusion secondary to perfusion abnormalities.

Key words: balloon occlusion, carotid artery, cerebral blood flow, ^{99m}Tc-HM-PAO

Introduction

The balloon occlusion test (BOT) is widely used to obtain reliable information regarding tolerance to internal carotid artery (ICA) occlusion during the management of various skull base lesions.[16] The BOT, combined with cerebral blood flow (CBF) studies in the normotensive state, helps identify patients who can tolerate ICA occlusion. However, the risk of ischemic complications resulting from hypotension, hypoxia, hypovolemia, or increased oxygen demand cannot be predicted.

Here, we report the use of the BOT combined with induced hypotension (provocative BOT) measurement of CBF using technetium-99m-hexamethyl-propyleneamine oxime (^{99m}Tc-HM-PAO). Our preliminary experience with the provocative BOT and simultaneous CBF mapping is presented.

Materials and Methods

This study investigated three patients with a large or giant aneurysm of the ICA (2 intracavernous and 1 at the C_1 portion) using the protocol shown in Fig. 1.

All procedures were performed under local anesthesia with the patient fully awake. Heparin (5000 IU, i.v.) was given at the beginning of the test. A 5-French double-lumen balloon catheter (Meditech, Inc., Watertown, Mass., U.S.A.) was then introduced through the femoral route, using a 7-French introducing sheath, and navigated into the cervical ICA. The balloon was positioned just above the bifurcation of the common carotid artery. The balloon was then inflated, using diluted contrast medium, to occlude the carotid flow temporarily. The arrest of flow was confirmed by a drop in the pressure and changes in the pulse wave and not by stagnation of the contrast medium since the latter could damage the intima of the ICA with subsequent

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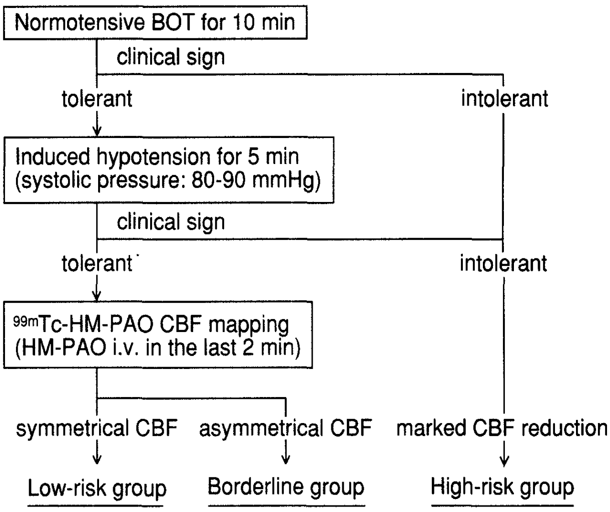

Fig. 1 Protocol for the provocative BOT with CBF mapping.

Fig. 2 Case 1. Preoperative left carotid angiogram, lateral view, showing an intracavernous ICA aneurysm.

exposure of the brain to an unnecessarily high concentration of the contrast medium. Neurological monitoring was continuous and the pressure in the distal ICA (stump pressure) was measured.

If the patient showed no neurological deterioration for about 10 minutes, hypotension (25–35% reduction in the systolic pressure, usually 80–90 mmHg) was induced using trimetaphan camsylate and maintained for about 5 minutes. During the last 2 minutes, 925 MBq (25 mCi) of ^{99m}Tc-HM-PAO (Amersham International Public Limited Co., Buckinghamshire, U.K.) was injected intravenously. This 2-minute period allows stable distribution of the radioactive agent. The patient was then shifted from the angio-suite to the rotating single photon emission computed tomography (Starcam; IGE Medical Systems Ltd., Herts, U.K.) room within 1–3 hours. The radioactivity in each hemisphere was counted using CBF mapping and the interhemispheric difference evaluated. If the patient showed ischemic symptoms, the balloon was immediately deflated and blood flow restored. Finally, protamine sulfate was used to reverse the effect of heparin.

Case Presentation

Case 1: A 54-year-old female developed sudden left retro-orbital pain and rapid deterioration of ocular movements on the same side. She had had hemifacial spasm for the last 3 years, but was otherwise healthy. Neurologically, she was alert with normal pupils but with left oculomotor and abducent nerve pareses. Left carotid angiograms showed a giant intracavernous ICA aneurysm (Fig. 2).

She tolerated the BOT under both normotensive (systemic pressure: 190/92 mmHg) and hypotensive (84/50 mmHg) conditions very well with the stump pressure 80/50 and 40/34 mmHg, respectively. No CBF studies were done.

Proximal balloon occlusion using three detachable balloons was carried out. A post-embolization CBF study showed only 4% lower flow on the left as compared to the right (Fig. 3). Follow-up after 9 months showed that she was doing well.

Case 2: A 58-year-old hypertensive female complained of rapid decline in the visual acuity on the right. Computed tomographic (CT) scans showed a right parasellar enhanced lesion. Right carotid angiograms showed a 2.0-cm ICA aneurysm at the $C_{2\text{-}3}$ portion (Fig. 4). Magnetic resonance (MR) images showed multiple bilateral small infarcts in the deep white matter in addition to the aneurysm.

She tolerated the BOT for 10 minutes (systemic pressure: 160/93 mmHg, stump pressure: 64/41 mmHg). Hypotension (125/79 mmHg, 44/38 mmHg) was induced with great caution, which she tolerated satisfactorily. CBF mapping during induced hypotension showed that flow in the right hemisphere was 18% less than that in the left (Fig. 5). However, we considered that she could tolerate the ICA occlusion.

The aneurysm was trapped using three balloons in a separate procedure. Heparin 10,000 IU daily and ticlopidine 100 mg *ter in die* were given postoperatively. She remained stable until 24 hours post-embolization when she developed sudden disturbance of consciousness and left hemiparesis. Hypervolemic hypertensive therapy did not improve her status.

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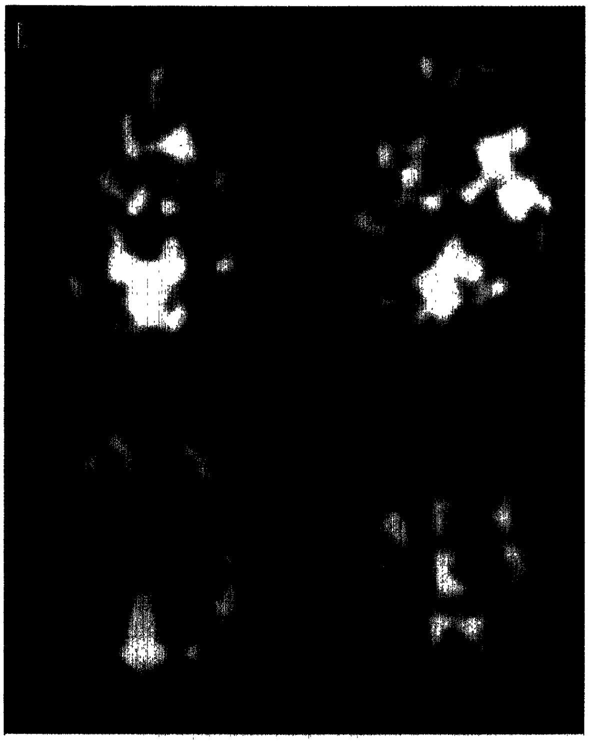

Fig. 3 Case 1. CBF maps following proximal balloon occlusion of the left ICA, showing minimal CBF reduction in the left parieto-occipital region. However, the percentage radioactivity reduction in the left hemisphere compared to the right is only 4%.

Fig. 5 Case 2. CBF maps during the right BOT with induced hypotension, showing the regional CBF reduction especially in the right deep white matter. Percentage radioactivity reduction in the right hemisphere compared to the left is 18%.

Fig. 4 Case 2. Preoperative right carotid angiogram, anteroposterior view, demonstrating a large aneurysm at the $C_{2\text{-}3}$ portion of the right ICA.

Fig. 6 Case 2. Left carotid angiogram, anteroposterior view, 3 days after ischemic complication, showing adequate collateral flow to the right hemisphere.

Left carotid angiograms 3 days later did not demonstrate the aneurysm or occlusion of any major vessel (Fig. 6). MR images 5 days after the deterioration showed fresh infarcts in the right deep white matter, in locations where CBF mapping had shown reduced blood flow (Fig. 7). After 7 months, follow-up showed that she was alert with left hemiparesis and needed support to walk.

Case 3: A 67-year-old male presenting with muscle-

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Fig. 7 Case 2. T_2-weighted spin-echo MR image 5 days after the ischemic complication, showing multiple infarcts within the right deep white matter, not present preoperatively.

contraction headache demonstrated an incidental giant ICA aneurysm on the left. The BOT was tolerated well in both normotensive (systolic pressure: 128/64 mmHg, stump pressure: 73/52 mmHg) and the hypotensive (86/48 mmHg, 63/31 mmHg) states. CBF mapping during hypotension showed a minimal CBF reduction on the left although there was no interhemispheric difference in radioactivity. No embolization/surgery was performed since he opted for observation and follow-up.

Results

Table 1 shows the systemic and stump pressures in the ICA during the normotensive and hypotensive states. The CBF study during hypotension was carried out in only two cases. In Case 1, it was performed after embolization in the normotensive state. There were no procedure-related ischemic complications. Only two of the three patients had a permanent ICA occlusion, one of whom developed ischemic problems 24 hours after occlusion. The study indicates that the patients may be grouped into three possible categories: 1) low-risk group tolerating the BOT well with symmetrical CBF mapping, 2) borderline group tolerating with asymmetrical CBF mapping, and 3) high-risk group intolerating to the test occlusion.

Discussion

Complications following ICA occlusion usually result from thromboembolism or hypoperfusion.[10] Prevention of thromboembolism is difficult, but hypoperfusion may be detected by serial neurological monitoring, measurement of stump pressure, angiographic cross-filling, electroencephalographic (EEG) monitoring, jugular venous blood sampling, dynamic CT, and CBF study following temporary ICA occlusion.[5,6,8,11,13,14,16,17,20,21]

Matas[12] pioneered tolerance tests to ICA occlusion in 1911. The introduction of interventional neuroradiology developed the BOT. Berenstein *et al.*[1] used the BOT (15-minute occlusion) in eight intracavernous ICA aneurysm cases. Higashida *et al.*[7] found transient cerebral ischemia in 10.3% and permanent stroke in 4.4% of 68 patients (30-minute occlusion with the stump pressure > 40 mmHg). Fox *et al.*[4] used 15-minute occlusion with serial neurological monitoring and found a 12.1% incidence of delayed ischemia and 1.7% of permanent stroke among 58 patients treated with ICA balloon occlusion.

Various parameters including stump pressure,[9] angiographic cross-filling,[8] and EEG monitoring[11] have been used to predict tolerance to ICA occlusion but none are totally reliable since the studies were carried out under otherwise normal conditions, without

Table 1 Case summary

Case No.	Age/Sex	Aneurysm		Symptom	Angiographic cross-filling	BOT tolerance	Stump pressure* (mmHg)	Systemic pressure* (mmHg)	CBF reduction (%)	Treatment	Outcome (Follow-up)
		Side	Size (cm)								
1	54/F	lt	2.6	ophthalmoplegia, retro-orbital pain	good	yes	80/50→40/34	190/92→84/50	4	proximal occlusion	good (9 mos)
2	58/F	rt	2.0	visual decline	good	yes	64/41→44/38	160/93→125/79	18	trapping	infarction (7 mos)
3	67/M	lt	3.2	none	?	yes	73/52→63/31	128/64→86/48	0	none	good (9 mos)

*Normotension→induced hypotension.

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considering the effect of hypotension, hypoxia, hypoglycemia, anemia, or increased oxygen demand in the presence of an occluded ICA.[15] Berenstein *et al.*[1] reported ipsilateral weakness associated with hypotension 2 hours after ICA occlusion. The deficit disappeared following normalization of the blood pressure. Terada *et al.*[20] similarly reported improvement in hemiparesis when the blood pressure was raised from 80 to 100 mmHg.

Sundt *et al.*[19] reported the critical CBF value, or minimal CBF required for a normal EEG under halothane anesthesia at a normal $PaCO_2$, as 18 ml/100 gm/min. In contrast, Leech *et al.*[11] found that carotid occlusion was safe if the CBF during carotid occlusion was more than 40 ml/100 gm/min and unsafe at less than 20 ml/100 gm/min. Carotid occlusion was also safe if the CBF was 20–40 ml/100 gm/min and the reduction less than 25% of the control value, or if the reduction was 25–35% and the stump pressure greater than 60 mmHg.

The ideal absolute CBF measurement with the xenon-133 inhalation method or stable xenon CT imaging takes about 10–20 minutes and involves shifting the patient from the angiographic to the CBF room with the balloon catheter *in situ*, increasing the risk of procedure-related complications. We used the HM-PAO CBF method since the material is distributed rapidly and is stable for a long time enabling short temporary occlusion and delayed CBF measurement. HM-PAO is always available for clinical use and can easily be employed even during emergency or short interventional procedures, giving three-dimensional CBF information with only about 2 minutes of flow arrest.[13] Hypotensive provocative BOT is not totally risk free and a quick deflation and restoration of blood pressure may be needed.[2]

Erba *et al.*[3] classified patients undergoing the BOT into four groups: Group 1 patients showing no significant CBF change with ICA occlusion; Group 2 patients with a symmetrical CBF decrease; Group 3 patients with an asymmetrical CBF decrease, the greater decrease on the occluded side; and Group 4 patients who failed to tolerate even a brief occlusion of the ICA. In this study, patients who tolerated the provocative BOT showing symmetrical CBF are considered to be the low-risk group with little risk of stroke. Those with an asymmetrical CBF (borderline group) have a moderate to high chance of developing post-occlusion stroke. Patients who cannot tolerate the BOT (high-risk group) have a very high risk of developing stroke. The latter two groups may therefore be considered for extracranial to intracranial bypass surgery.[6,18]

Our Case 2 was considered suitable for carotid occlusion according to the criteria of Leech *et al.*[11] since 18% less ^{99m}Tc-HM-PAO radioactivity than the healthy side indicates a CBF reduction within 25–35%, the stump pressure was greater than 60 mmHg, and the patient tolerated the provocative BOT. However, she developed thromboembolic ischemia 24 hours after the ICA occlusion, which could not be predicted even by the provocative BOT. Following Leech *et al.*, we feel that close neurological monitoring for about 3 days in intensive care with a gradual return to activity is needed postoperatively. The presence of the asymptomatic multiple cerebral infarcts on MR images as in Case 2 may indicate a high risk to post-occlusion stroke.

The BOT is an attempt to study the immediate/early effects of carotid occlusion. Simulation of the natural hemodynamic changes including late change and long-term effects following carotid occlusion cannot be assessed by such temporary occlusion tests. However, the BOT can help identify high-risk patients and the provocative hypotension test is more useful. Nonetheless, a better understanding/interpretation of the BOT and results is required.

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