Evaluation of Cerebral Collateral Circulation by Technetium-99m HM-PAO Brain SPECT During Matas Test: Report of Three Cases

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Three cases with cerebral ischemic symptoms and an intracranial aneurysm are presented. Using [^{99m}Tc]hexamethyl-propyleneamine oxime (HM-PAO) single photon emission computed tomography imaging before and during the Matas test, a quantitative measurement method was developed for evaluating brain collateral circulation. The evaluation correlated well with findings of contrast carotid angiography. This noninvasive method seems to be useful for selection of patients for appropriate surgical treatment.

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Many surgeons recommend a trial period of carotid occlusion before vascular surgery for assessing the efficacy of brain collateral circulation, especially in patients in whom temporary or permanent carotid artery ligation is mandatory. This procedure, known as the Matas' test (*1*), can be performed either percutaneously during contrast angiography or on operative exposure of the carotid vessels in the neck. In the present study, we developed a noninvasive nuclear medicine procedure combined with the Matas test for evaluating brain collateral circulation.

MATERIALS AND METHODS

For the first step, 20 mCi of technetium-99m (^{99m}Tc) hexamethylpropyleneamine oxime (Amersham International plc, Buckinghamshire, UK) (HM-PAO) was injected intravenously with the patient lying supine and the head fixed to obtain single photon emission computered tomographic (SPECT) images before the Matas test. After 5 min postinjection acquisition of projection data was started using a rotating gamma camera system (Siemens ZLC/7500, Siemens Gammasonics Inc., Des Plaines, IL) equipped with a fan beam collimator and combined with a minicomputer (Scintipac 2400, Shimadzu Co., Kyoto, Japan) for 60 angles with 15 sec per angle. For the second step, without any change in the patient's head position, the common carotid artery on the affected side was compressed manually by a neurosurgeon for 5 min. The additional dose of 20 mCi of HM-PAO from the same vial as in the first step was injected 30 sec after starting the compression. The artery was compressed sufficiently to stop blood flow distal to the compressed site. Immediately after the compression, the second data acquisition was started in the same manner as in the first. The filtered backprojection method (*2*) was used for image reconstruction. No attenuation correction was performed. The slice thickness was 12 mm. After reconstruction the tomographic images in the first step were subtracted from the images in the second step to obtain those during the Matas test.

Regions of interest (ROIs) were drawn over the middle cerebral artery (MCA) territories, the anterior cerebral artery (ACA) territories, and cerebellar regions in the transaxial tomographic images. Since the blood supply of the cerebellum is derived from the vertebral arteries and may not be affected by compression of the common carotid artery, we chose this area as a reference. Then percent activity change of MCA or ACA territory during the Matas test was calculated as follows:

% activity change during the Matas test

$$= 100\ (1 - (Ci^d/Cr^d)/Ci^b/Cr^b)), \tag{1}$$

where Ci_b/Cr_b and Ci_d/Cr_d are the relative activity ratio of MCA or ACA territory (Ci) to the cerebellum (Cr) before (b) and during (d) the Matas' test, respectively.

CASE REPORTS

Case 1

A 67-yr-old man with a previous history of diabetes mellitus and hypertension was admitted because of right-sided mus-

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cular weakness and speech disturbance. On physical examination dysarthria and right hemiparesis were noted. X-ray computed tomography (CT) scan showed low density areas in the left corona radiata and in bilateral caudate nuclei (Fig. 1A). Left carotid angiography revealed 60% stenosis in the cervical portion of the left internal carotid artery. Right carotid angiography during the left-sided Matas test revealed nonfilling of the left MCA due to hypoplasia of the most proximal portion (A_1 portion) of the left ACA (Fig. 1B). HM-PAO images before the Matas test did not show focal perfusion reduction, while 19% activity reduction in the left MCA territory was noted during the left-sided Matas test (Fig. 1 C–E). This patient has been followed up without endarterectomy.

Case 2

A 67-yr-old man with a previous history of transient consciousness loss was admitted because of right-sided muscular weaknesses. On physical examination positive Barre sign and decreased grasping power were noted on the left side. X-ray CT scan showed a low density area in the left corona radiata (Fig. 2A). Left carotid angiography detected 50% stenosis in the left internal carotid artery. Right carotid angiography during the left-sided Matas test revealed filling of bilateral ACA and MCA (Fig. 2B). HM-PAO images before the Matas' test did not demonstrate focal perfusion reduction, and quantitative measurement showed only 3% activity reduction in the left MCA territory during the left-sided Matas' test (Fig. 2 C–E). This patient was operated because of the presence of good collateral circulation. Clamp of the left carotid artery for 38 min during endarterectomy did not result in any complication.

Case 3

A 73-yr-old female without any distinctive previous medical history was admitted because of blephaloptosis on the right side. On physical examination only right-sided blephaloptosis was noted with a maximum width of 5 mm right eye fissure. X-ray CT scan showed a round area with slight high density on the right side of sella turcica with marked contrast enhancement (Fig. 3A). Right carotid angiography revealed a giant aneurysm in the cavernous portion of the right internal carotid artery. Left carotid angiography during the right-sided Matas test (Fig. 3B) revealed nonfilling of the left ACA including A_1 portion except for the most distal portion filled from the leptomeningeal anastomosis with the left posterior cerebral artery. Bilateral ACA territories were opaqued in right carotid angiography (Fig. 3C). HM-PAO images before the Matas test did not demonstrate any perfusion reduction, while 28%, 29%, and 22% activity reductions were noted in the right ACA territory, in the right MCA territory, and in the left ACA territory, respectively, during the right-sided Matas test (Fig. 3 D–F). Although ligation of the right carotid artery had been planned for this giant aneurysm within the cavernous sinus because of the inaccessibility, it was abandoned due to poor collateral circulation.

DISCUSSION

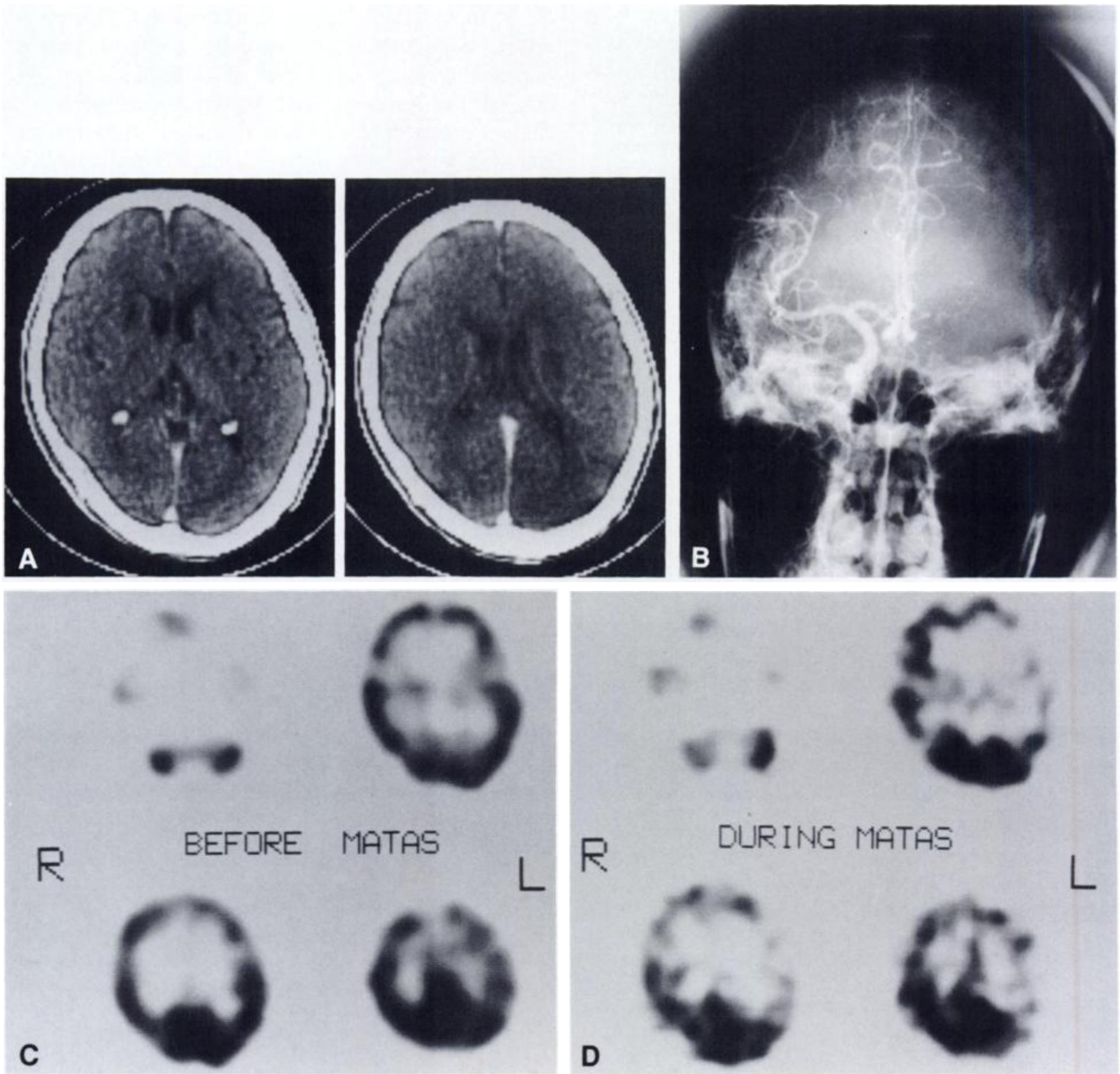
HM-PAO is a new tracer for evaluating brain perfusion (*3*). It has the specific property of excellent retention at steady state (*4,5*). Its distribution pattern in the brain tissue is determined in a short period and kept for a long time after intravenous injection. This property is quite useful for evaluating perfusion change during interventional studies of short duration. We applied this property here to investigate perfusion change during the Matas test. A similar interventional study was reported by Biersack et al. (*6*) during unilateral hemispheric anesthesia, in which perfusion studies before and during the test were performed on different days. In the present study, unlike the previous report, we combined a perfusion study during the test with that before the test as a consecutive study. This combination enabled us to perform the whole study within 45 min and to obtain identical slices to compare the results before and during the test with little motion artifact of the patient's head.

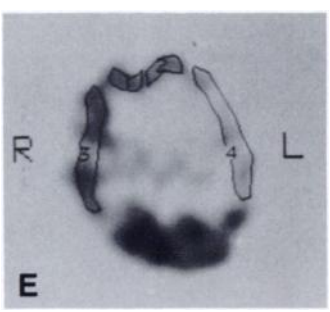
A problem in this study is the difficulty in administrating equal doses of HM-PAO in the consecutive two studies. Even if we inject the same radioactivity to a patient in the second step as in the first step, we cannot expect the administration of an equal dose of HM-PAO between the two steps since the radiochemical purity of HM-PAO gradually decreases with time after preparation (*3*). We resolved this problem using the cerebellar activity as a reference. The Matas test to the common carotid artery is assumed to have no influence on perfusion changes of the cerebellum because of the different systems of blood supply. Furthermore, we chose an ipsilateral cerebellar hemisphere to the affected side as a reference region to escape an influence of crossed cerebellar diaschisis (*7*).

Nonproportionality between brain activity and blood flow has been suggested by Lassen et al. in HM-PAO studies (*8,9*). To linearize the curvilinear relationship (*8,9*) between brain activity of HM-PAO and flow with a slope that decreases for high flow values, the following equation has been proposed (*8,9*).

$$\mathrm{fi}/\mathrm{fr} = \alpha\,(\mathrm{Ci}/\mathrm{Cr})/(1 + \alpha - \mathrm{Ci}/\mathrm{Cr}), \qquad (2)$$

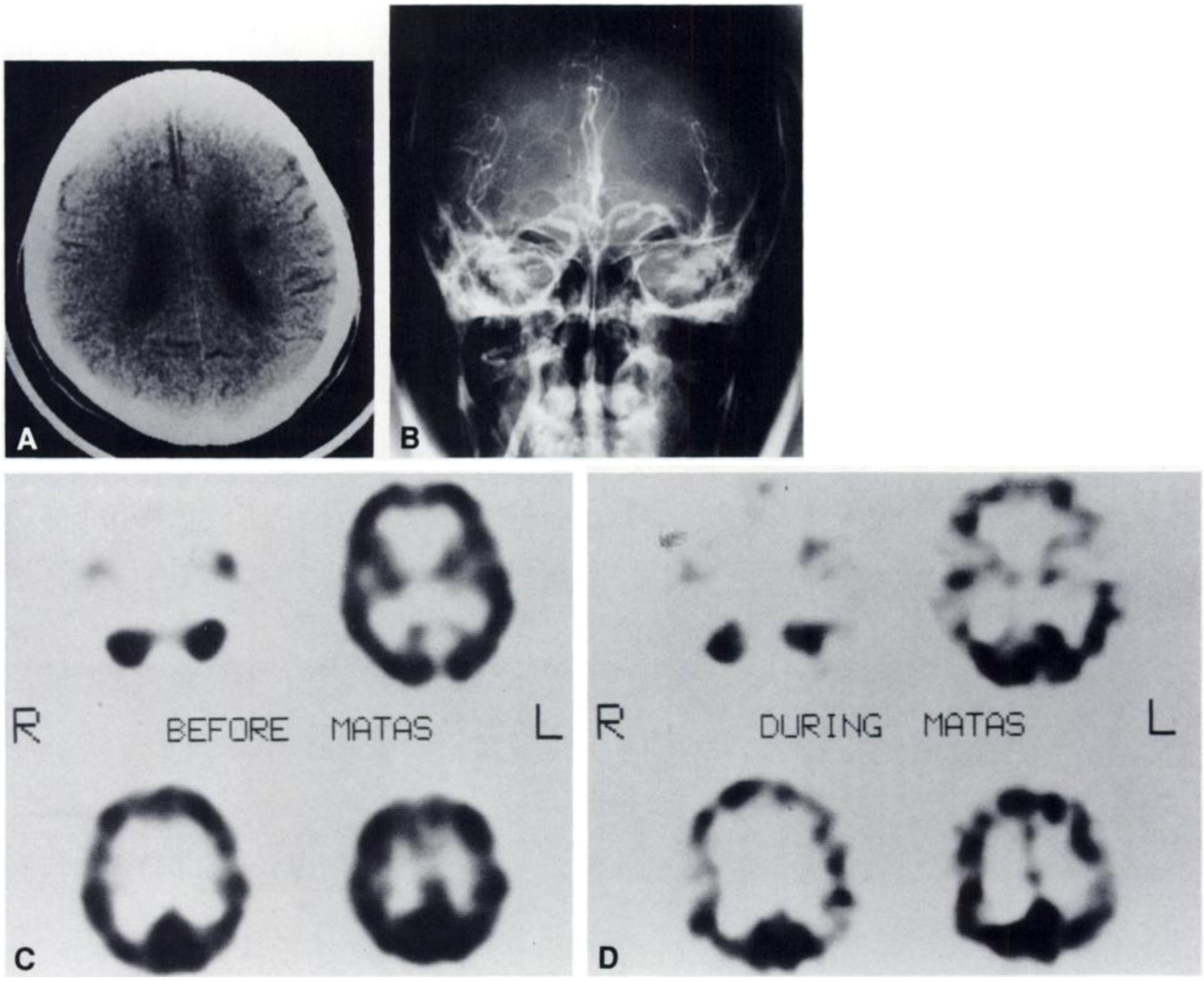
where fi and fr are flow for a region and a reference region respectively, and Ci and Cr are radioactivities for the region and the reference region respectively. The alpha is a correction factor for the linearization, the appropriate value of which is reported to be 1.5 (*8,9*). Employing this Eq.(2) resulted in more prominent percent flow changes in the first and third cases in the present study as described in Figure 1E and Figure 3F. For example, in the third case, the flow reduction in the left MCA territory was calculated as 38% after the correction, while the activity reduction was 29%. However, even if the activity change is underestimated from the true flow change, the distinct differences are demonstrated in activity changes between ill-perfused and well-perfused regions during the Matas test. Therefore correction for the linearization does not seem to be necessary.

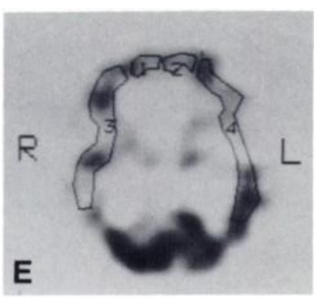




ROI	Territory	Activity Change (Flow Change)
1	Right ACA	0% (1% decrease)
2	Left ACA	3% decrease (6% decrease)
3	Right MCA	2% increase (4% increase)
4	Left MCA	19% decrease (27% decrease)

FIGURE 1
A: X-ray CT scan of a 67-yr-old patient with dysarthria and right hemiparesis showing low density areas in the left corona radiata and in bilateral caudate nuclei. B: Right carotid angiogram during the left-sided Matas test showing nonfilling of the left MCA due to hypoplasia of the most proximal portion of the left ACA. C: Transaxial brain perfusion images using HM-PAO before the Matas test showing no focal perfusion reduction. D: Transaxial brain perfusion images during the left-sided Matas test showing decreased perfusion in the left MCA territory. E: Quantitative analysis of regional activity changes during the test using Eq. (1). Figures in parentheses are flow changes calculated from Eq.(2).

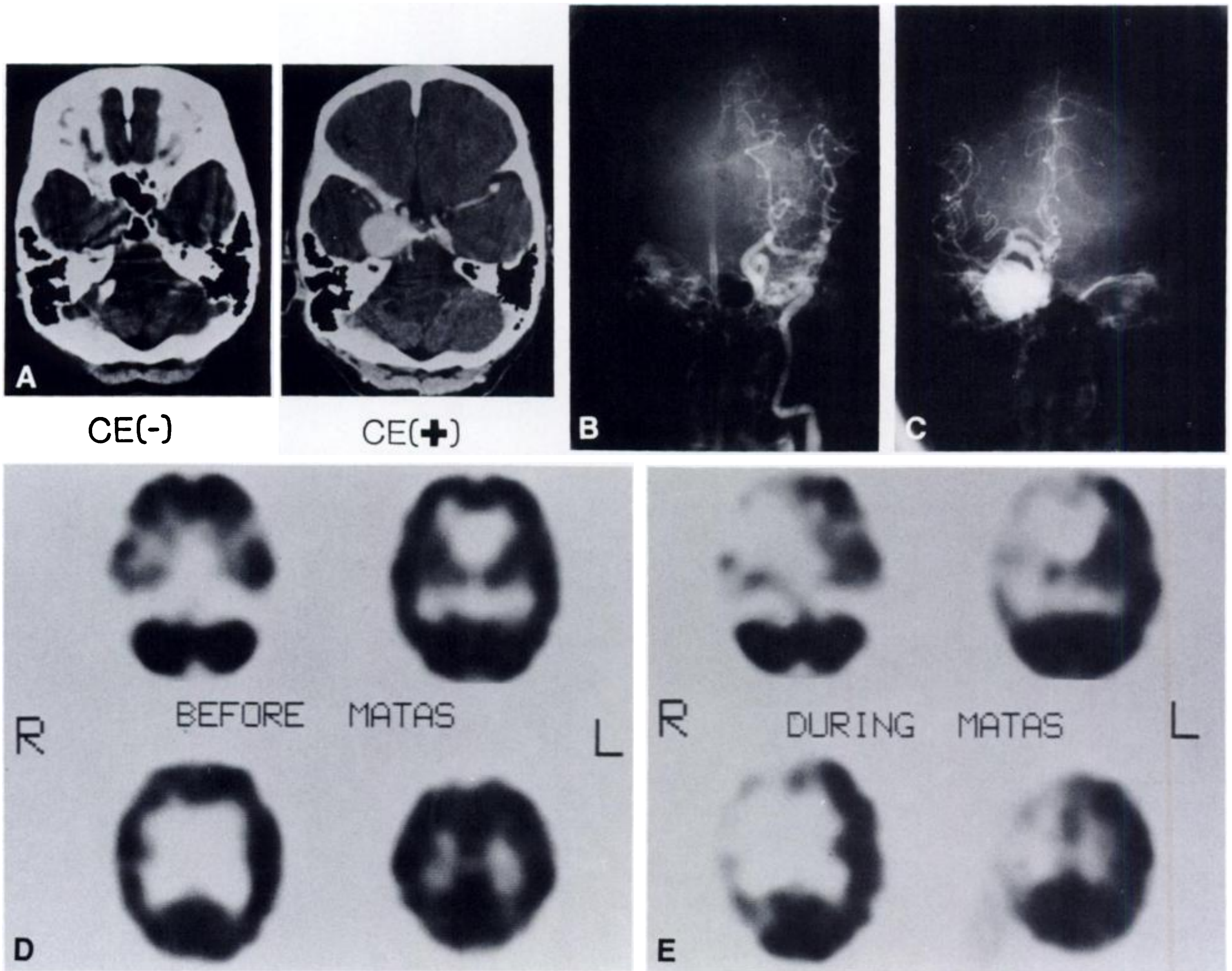


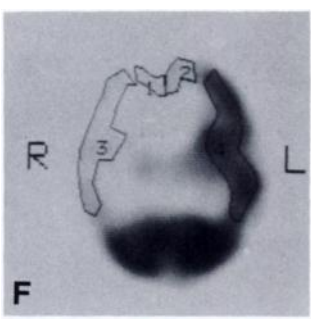


ROI	Territory	Activity Change (Flow Change)
1	Right ACA	1% increase (2% increase)
2	Left ACA	0% (0%)
3	Right MCA	4% decrease (3% decrease)
4	Left MCA	3% decrease (4% decrease)

FIGURE 2
A: X-ray CT scan of a 67-yr-old patient with right hemiplegia showing a low density area in the left corona radiata. B: Right carotid angiogram during the left-sided Matas test showing good filling of bilateral ACA and MCA. C: Transaxial brain perfusion images using HM-PAO before the Matas test showing no focal perfusion reduction. D: Transaxial brain perfusion images during the left-sided Matas test showing no significant reduction in the left hemisphere. E: Quantitative analysis of regional activity changes during the test using Eq.(1). Figures in parentheses are flow changes calculated from Eq.(2).

It has been reported that quantitation of absolute blood flow values using HM-PAO is difficult because of rapid conversion of the diffusible tracer to the non-diffusible one in blood (*10,11*) and initial back diffusion of the diffusible tracer from brain to blood (*8,9*). It is a drawback for HM-PAO in comparison with the relative ease in quantitating absolute blood flow values using N-isopropyl-(^{123}I)p-iodoamphetamine (IMP) (*12–14*). Nevertheless, the two-step HM-PAO study of short duration is quite useful for quantitatively evaluating





ROI	Territory	Activity Change (Flow Change)
1	Right ACA	28% decrease (36% decrease)
2	Left ACA	22% decrease (21% decrease)
3	Right MCA	29% decrease (38% decrease)
4	Left MCA	1% decrease (2% increase)

FIGURE 3
A: X-ray CT scan of a 73-yr-old patient with right blephaloptosis showing a round area with slight high density (CE(−)) on the right side of the sella turcica with marked contrast enhancement (CE(+)). B: Left carotid angiogram during the right-sided Matas test showing nonfilling of the left ACA except for the most distal portion filled from the leptomeningeal anastomosis with the left posterior cerebral artery. C: Right carotid angiogram showing a giant aneurysm in the cavernous portion of the right internal carotid artery and filling of bialateral ACA. D: Transaxial brain perfusion images using HM-PAO before the Matas test showing no focal perfusion reduction. E: Transaxial brain perfusion images during the right-sided Matas test showing focal reductions in the right MCA and bilateral ACA territories. F: Quantitative analysis of regional activity changes during the test using Eq.(1). Figures in parentheses are flow changes calculated from Eq.(2).

perfusion change during intervention. The time-dependent change of IMP distribution in the brain (*14, 15*) makes such a repetitive study in a short interval impossible.

In the previous report using intra-arterial Xenon-133 (^{133}Xe) clearance method during the Matas test (*16*), 25% flow reduction is considered as the critical point in deciding the feasibility of carotid artery ligation since more than 25% flow reduction induced hemiparesis. In the present three cases, no patient suffered from hemiparesis during the Matas test of 5 min duration in HM-PAO studies. However, the third case manifested transient left hemiparesis during the right-sided Matas test of 6 min duration performed on a different day. In contrast, the first case did not manifest hemiparesis during the test of even 40 min duration. From these results the critical point could exist between 19% and 29% reduction in radioactivities. Since we described here only three cases, further studies should be continued to determine the critical level in this method. This noninvasive three-dimensional method is considered as a more appropriate study than the two-dimensional ^{133}Xe clearance method for precise assessment of regional perfusion changes.

Our observations were compatible with contrast angiographic findings. However, the most important information in the Matas test was pointed out to be flow changes at the capillary level (*17*), which are easily obtained from this nuclear medicine technique. Ill-perfused regions during the test are clearly detectable by visual inspection. In addition we succeeded in quantitating perfusion change.

HM-PAO SPECT studies before and during the Matas test seem to be a valuable, noninvasive, and quantitative method for evaluating the efficiency of cerebral collateral circulation via the circle of Willis. Using this study there arises the possibility that we can select the patients that will tolerate temporary or permanent carotid artery ligation. Complementary use of this study and contrast angiography makes the Matas test more reliable for the ligation of the carotid artery.

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