

# Positron Emission Tomography Studies of Changes in Cerebral Blood Flow and Oxygen Metabolism in Arteriovenous Malformation of the Brain

(With 1 color plate)

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**Key Words.** Arteriovenous malformation · PET · Seizure · Transient focal neurological deficit

**Abstract.** Two patients with arteriovenous malformation were studied by positron emission tomography, using the steady-state technique with <sup>15</sup>O<sub>2</sub>. In the first patient, who had seizures, preceded by auditory hallucinations, an area of decreased cerebral blood flow and oxygen consumption was shown just behind the malformation. In the second patient, who had repeated attacks of right hemiparesis, an area of decreased blood flow and oxygen metabolism was shown at distance of the malformation. These areas of low flow and metabolism are most probably the result of a vascular steal phenomenon and the origin of the transient neurological symptoms in both patients.

## Introduction

Arteriovenous malformations consist of a tangle of dilated vessels, which form an abnormal communication between the arterial and venous systems. Half of the patients present with a cerebral haemorrhage, 30% with a seizure and 20% with migrainous headache or a transient neurological deficit [1]. The aim of the study is to analyse by means of positron emission tomography (PET) the possible mechanisms that had caused temporary disturbances of brain function in 2 patients with arteriovenous malformations.

## Patients and Methods

### Patients

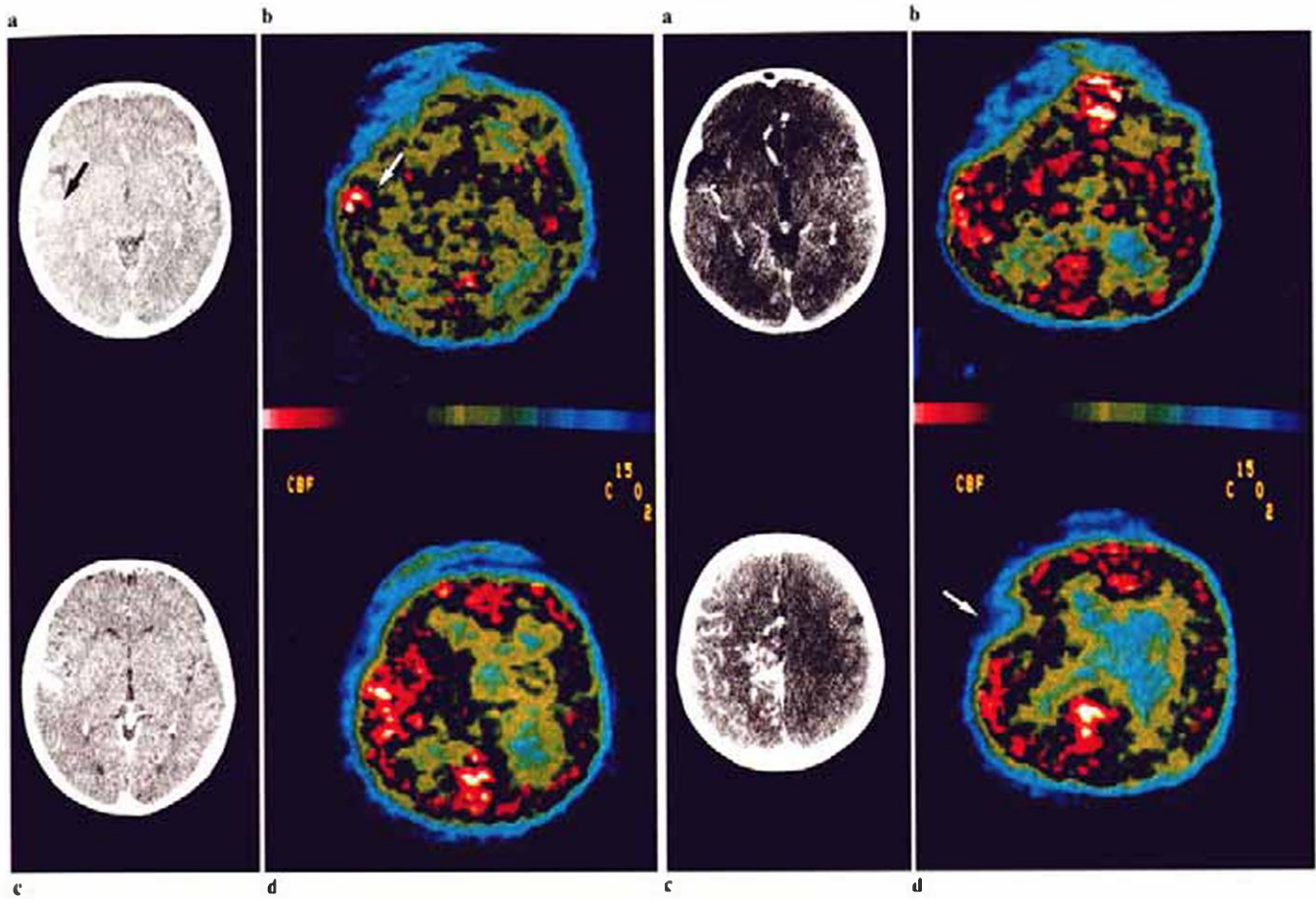
**Patient 1.** A 48-year-old man had a history of two episodes of auditory hallucinations with subsequent loss of consciousness and generalized convulsions.

Neurological examination on admission was normal. Computed tomography (CT) scan of the brain and angiography demonstrated a small arteriovenous malformation in the left insular region. The

malformation was already filled in the early arterial phase and drained by a large vein to the lateral sinus.

**Patient 2.** A 65-year-old right-handed woman had a history of recurrent convulsions, starting at the right leg with secondary generalization, from the age of 35 years on. A large arteriovenous malformation, fed by the end branches of the left anterior cerebral artery, in the left parietal region, was demonstrated by angiography at the age of 42 years. The malformation was considered not to be surgically removable. Although high doses of anti-epileptic drugs were given, this patient still had recurrent epileptic fits, but also transient episodes of right hemiparesis.

In 1984, a partial embolization of the malformation was performed. Afterwards the patient had no more seizures, but the episodes of transient hemiparesis recurred approximately every 2 months. CT scan of the brain demonstrated only the malformation at the medial side of the left cerebral hemisphere. No infarction was observed. Left carotid angiography showed a dilated left anterior cerebral artery, feeding a large medial parietal arteriovenous malformation. Venous drainage appeared in the early arterial phase. The branches of the left middle artery were visible at the same time as the malformation. The right carotid angiography showed poor opacification of the right anterior cerebral artery, by draining of the contrast media to the left anterior cerebral artery by the anterior communicating artery. The branches of the right middle cerebral artery were well filled.



**Fig. 1.** Comparison of the CT scan (a, c) with the  $^{13}\text{CO}_2$  scan (b, d) in two slides, respectively, 3 mm (a, b) and 35 mm (c, d) above the orbitomeatal line in patient 1. The left arteriovenous malformation (arrow) can be picked up on the CT scan as well as on the CBF scan (a, b). In addition, increased flow is demonstrated in the upper cortical regions and the basal ganglia of the left hemisphere.

**Fig. 2.** Comparison of the CT scan (a, c) with the  $^{13}\text{CO}_2$  scan (b, d) in two slides, respectively, 3 mm (a, b) and 35 mm (c, d) above the orbitomeatal line in patient 2. The arteriovenous malformation, drained by the left anterior cerebral artery, and a zone of increased rCBF in the territory of the feeding vessels are shown. In addition, a restricted area of decreased flow is demonstrated at the convex side of the left cerebral hemisphere (d, arrow). No corresponding structural change can be shown on the CT scan.

On neurological examination between the attacks, only brisk tendon reflexes and a Babinski sign on the right side, without loss of strength, were found.

*PET Scan*

For the measurements of the regional blood flow (rCBF), oxygen extraction rate (rOER) and oxygen consumption (rCMRO<sub>2</sub>), the procedures were essentially similar to those described by Frackowiak et al. [2].

A Neuro-Ecat PET scanner (EG&Ortec, Oak Ridge, Tenn., USA), equipped with 2 rings of detectors and with lateral and axial resolution of 8.1 and 14.0 mm, respectively, were used. The distance between the centres of the 2 detector rings was 32 mm.

After a blanco scan had been performed with an external germanium-68 ring source, the head of the patient was positioned to allow the accumulation of data from 2 coronal slices, with their centres 3 and 35 mm above the orbitomeatal line. Thereafter, a transmission scan was performed with the external germanium-68 ring source to measure photon attenuation and to correct the subsequent emission scans.

For measuring rCBF, <sup>15</sup>CO<sub>2</sub> was inhaled by the patient at a rate of 20 µCi/min. After 10 min of equilibration, the radioactivity in the head was scanned during 300 s. Two arterial blood samples were obtained anaerobically at the beginning and at the end of the scan.

For measuring rOER, <sup>15</sup>CO<sub>2</sub> was inhaled at a rate of 40 µCi/min, and, after an equilibration period of 10 min, the scan time was extended to 400 s and also two arterial blood samples were taken anaerobically at the beginning and at the end of the procedure.

The measurement of the radioactivity in the blood samples and the rCBF, rOER and rCMRO<sub>2</sub> determinations were calculated according to the methods described by Weyne et al. [3].

Several cortical regions, basal ganglia and white matter of the cerebral hemisphere with the arteriovenous malformation were examined separately and the values obtained were compared with those of the corresponding regions of the contralateral hemisphere.

Statistical significance was determined by test for paired values and p values of less than 0.05 were considered to be significant.

**Results**

*Patient 1*

The rCBF, rOER and rCMRO<sub>2</sub> values obtained 14 days after the last epileptic fit are shown in table 1.

In the left frontal and anterior temporal cortical areas, the values for rCBF and rCMRO<sub>2</sub> are increased by more than +100%, while the changes in rOER are similar to those of the corresponding regions in the non-affected hemisphere.

Also in the left basal ganglia, a deviation of +65% is found for rCBF and rCMRO<sub>2</sub>, with comparable values for rOER between the left and right side. On the other hand, the rCBF is lowered to 70% and the rCMRO<sub>2</sub> to

62% in the left parietotemporal cortex, lying behind the arteriovenous malformation.

The CT scan of the corresponding sections shows only a small contrast in the left insular region. No other structural lesions are observed (fig. 1).

*Patient 2*

PET scan was performed in this patient 7 days after the last episode of transient right hemiparesis. The values of rCBF, rOER and rCMRO<sub>2</sub> are shown in table 2. In the medial cortical part of the left cerebral hemisphere, the increase of rCBF is approximately +115% and that of rCMRO<sub>2</sub>, +96%, with no significant deviation of the rOER. In the area where the large malformation is

**Table 1.** Comparison of the rCBF, rOER and rCMRO<sub>2</sub> between different regions of the left (L) cerebral hemisphere with the arteriovenous malformation and the right (R) cerebral hemisphere in patient 1 (p < 0.05)

| Hemisphere region        |   | rCBF ml/min/100 g | rOER % | rCMRO <sub>2</sub> ml/min/100 g |
|--------------------------|---|-------------------|--------|---------------------------------|
| Anterior insular cortex  | L | 104.6             | 61.2   | 9.9                             |
|                          | R | 50.3              | 59.5   | 4.6                             |
| Posterior insular cortex | L | 36.2              | 61.1   | 3.2                             |
|                          | R | 51.7              | 65.5   | 5.2                             |
| Frontal cortex           | L | 68.2              | 53.8   | 6.2                             |
|                          | R | 38.3              | 50.2   | 3.6                             |
| Basal ganglia            | L | 48.9              | 49.1   | 4.8                             |
|                          | R | 29.4              | 53.3   | 3.0                             |

**Table 2.** Comparison of rCBF, rOER and rCMRO<sub>2</sub> between different regions of the left (L) cerebral hemisphere with the arteriovenous malformation and the right (R) cerebral hemisphere in patient 2 (p < 0.05)

| Hemisphere region      |   | rCBF ml/min/100 g | rOER % | rCMRO <sub>2</sub> ml/min/100 g |
|------------------------|---|-------------------|--------|---------------------------------|
| Medial frontal cortex  | L | 121.3             | 59.9   | 12.2                            |
|                        | R | 55.9              | 66.7   | 6.6                             |
| Medial parietal cortex | L | 126.8             | 57.8   | 11.6                            |
|                        | R | 51.9              | 68.8   | 5.8                             |
| Lateral frontal cortex | L | 18.4              | 53.7   | 1.7                             |
|                        | R | 37.1              | 54.4   | 3.9                             |

present, the rCBF increases up to more than 400% and the rCMRO<sub>2</sub> up to more than 250%. In the frontoparietal region at the convex side of the left cerebral hemisphere, a significant decrease of rCBF of 50% and of rCMRO<sub>2</sub> of 58% is observed, without deviation of the values of rOER.

The CT scan of comparable sections can only demonstrate the large arteriovenous malformation at the medial side of the left cerebral hemisphere (fig. 2).

### Discussion

In the 2 patients examined, an increased CBF and CMRO<sub>2</sub> are shown in the regions lying in the supply area of the feeding vessels of the arteriovenous malformation.

Even in the first case with only a small malformation in the insular region, high values of rCBF and rCMRO<sub>2</sub> are found in an extensive zone of the left cerebral hemisphere.

As we have no normal controls one cannot exclude that flow and oxygen metabolism in the contralateral hemisphere are diminished. Neither have we determined the regional blood volume, which can be important for a more precise determination of the rCMRO<sub>2</sub>. Omitting such corrections leads to a systematic overestimation of OER, that increases with increasing cerebral blood volume [4]. However, in both cases, the rOER values are comparable in the corresponding regions of both cerebral hemispheres.

This allows to postulate that the impact of the malformation as a 'blood lake' does not interfere to much in the determination of the CMRO<sub>2</sub>. In spite of these limitations, we can put forward that the regions of increased CBF and CMRO<sub>2</sub> extend far beyond the anatomical limits of the arteriovenous malformation and that even in case of a small malformation the disturbances of flow and metabolism are extensive [5–10]. Also in both cases other regions have lowered rCBF and rCMRO<sub>2</sub>. Their decrease is probably responsible for the temporary brain dysfunction.

In the first case, the auditory hallucinations as aura of the epileptic insults can have their origin in the left auditory cortex of the post-insular region with low rCBF and rCMRO<sub>2</sub>. Epileptic foci interictally are frequently recognized as areas of low metabolism and blood flow [11–13].

In the second case, the finding of a zone of low rCBF and rCMRO<sub>2</sub> in the left upper frontoparietal region can

explain the periods of transient hemiparesis without speech disturbances. The values found for those regions suggest ischaemic infarction [14], not seen on the corresponding slides of the CT scan.

Concerning the cause of the cerebral hypoperfusion of some regions adjacent or at distance from the arteriovenous malformation several hypotheses can be discussed. Vasospasm occurs rarely in arteriovenous malformations [15, 16], and is associated with the presence of a subarachnoid bleeding, which is not the case in our 2 patients. Diaschisis has been described as a phenomenon of reduction of rCBF in uninvolved areas distant from an acute stroke [17]. This has never been described to occur in arteriovenous malformations. So the most probably cause of the low rCBF and rCMRO<sub>2</sub> is an intracerebral arterial steal phenomenon, caused by the shunting of blood through the arteriovenous malformation.

This phenomenon has already been demonstrated to occur frequently in these conditions, as well in regions adjacent to the malformation as in remoted areas [6, 18–20].

### Acknowledgments

This study was supported by a grant of the Scientific Research Committee of the Departments of the Prime Minister (no. O.O.A.12053 B85).

We would like to thank Prof. J. Weyne, Dr. G. De Ley, Prof. G. De Meester, Dr. K. Stryckmans, Dr. P. Goethals and Mr. De Kesel for their technical assistance and help.

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Received: December 2, 1988

Accepted: March 6, 1989

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