

Functional PET scanning in the assessment of cerebral arteriovenous malformations

Case report

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✓ A case is presented which represents the first instance of the use of functional positron emission tomography (PET) scanning to precisely localize a structural brain lesion to the precentral gyrus, and the first validation of functional PET scanning by intraoperative cortical mapping. The lesion was a 3-cm arteriovenous malformation (AVM) that had produced a generalized seizure in an otherwise asymptomatic young woman. A first, resting H₂¹⁵O PET scan identified the AVM. A second PET scan, performed during vibrotactile stimulation of the contralateral hand, identified the somatosensory area of the hand region and localized the AVM to that part of the precentral gyrus immediately in front of it. This relationship and localization were confirmed by cortical mapping at the time of craniotomy under local anesthesia. Functional PET scanning may prove to be useful to localize cortical lesions precisely and to help in determining preoperatively the best form of treatment for lesions, especially AVM's, in functionally important cortex.

KEY WORDS • arteriovenous malformation • cerebral blood flow • radiosurgery • functional localization • positron emission tomography

THE surgical results in cerebral arteriovenous malformations (AVM's) largely depend on the size of the lesion, the number of its feeding arteries, the complexity of its drainage system, and its proximity to eloquent brain regions.¹² Current neuroradiological imaging techniques can well demonstrate the morphology and vascular anatomy of cerebral AVM's and their relationship to deep gray nuclei, important white matter tracts, and the ventricular system.^{6,7} These imaging techniques cannot, however, reliably establish the relationship of the AVM to functionally important cortex. In the past this relationship has been established at craniotomy by cortical mapping under local or general anesthesia.^{1,8} Positron emission tomography (PET) offers the possibilities of imaging the AVM and of identifying eloquent cortex, such as pre- and postcentral functional areas, thus establishing the relationship between the pathological structure and cortical function.^{3,11} We describe our technique of functional PET scanning and offer evidence obtained from intraoperative cortical mapping of a patient with a cerebral AVM that establishes the validity of this technique.

Case Report

This 40-year-old right-handed woman came to the hospital following a single generalized seizure. She had previously been well, and detailed questioning elicited no history suggesting a previous intracranial hemorrhage.

Examination. Her physical examination was normal. Computerized tomography (CT), magnetic resonance (MR) imaging, and cerebral angiography demonstrated a 3-cm AVM in the vicinity of the left central region (Fig. 1A). The patient volunteered to undergo functional PET scanning with the understanding that the findings, if any, would not alter our treatment plan as she represented the first patient with a cerebral AVM to undergo this examination. Informed consent was obtained according to the guidelines of our institution's Ethics Committee. After discussion of the therapeutic options, the patient elected to undergo craniotomy with the understanding that if the AVM involved the motor strip it would not be excised but might be treated at a later date by stereotactically focused radiotherapy.

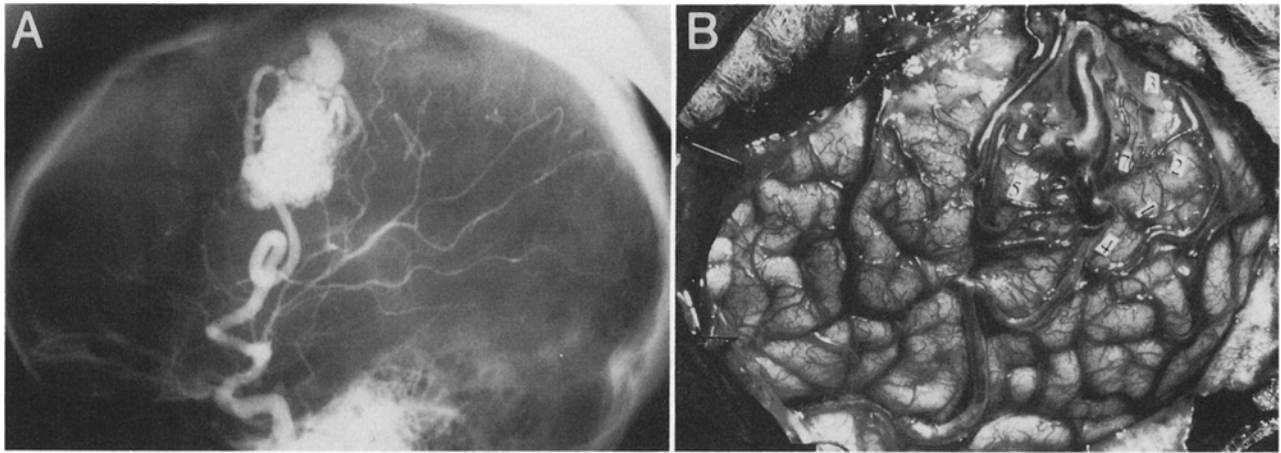


FIG. 1. *A*: Carotid angiogram demonstrating an arteriovenous malformation (AVM) in the vicinity of the left central region. *B*: Operative photograph demonstrating the superficial portion of the AVM within the precentral gyrus, and its relationship to the pre- and postcentral hand areas. Electrical stimulation at 2 V produced tingling of the third, fourth, and fifth digits (Nos. 1 and 2) and of the thumb (No. 4) of the right hand and of the right elbow and shoulder (No. 3). Stimulation at point No. 5 produced twitching of the mouth, grunting, and self-limited tonic-clonic movements of the right arm. Stimulation at 3 V (No. 7) produced flexion of the five digits of the right hand, as in making a fist, and flexion of the right wrist.

Operation. A left frontoparietal craniotomy was performed under local anesthesia, and intraoperative cortical mapping and intracarotid fluorescein angiography were carried out as previously described.⁸ The superficial aspect of the AVM was immediately apparent on gross inspection (Fig. 1B). Fluorescein angiography identified the major arteries supplying the lesion and those supplying the surrounding brain; it also demonstrated the smaller vessels of the nidus and identified large draining veins submitted to shunt flow, differentiating these bright red draining channels from enlarged feeding arteries.

Cortical mapping identified the postcentral gyrus behind the AVM, where positive responses of tingling sensations were obtained in the first, third, fourth, and fifth digits of the right hand and in the right elbow and shoulder (Fig. 1B). Stimulation of the gyrus immediately in front of the sensory hand region, in the area of the AVM, produced motor responses of the right hand and wrist and (more inferiorly) of the face, localizing the AVM to the precentral gyrus in the hand and arm areas of cortical representation (Fig. 1B). The major arteries supplying the AVM were identified and clipped in series, with repeat fluorescein angiography used to confirm that no ischemic injuries were incurred by the surrounding eloquent cortex. Clipping of the feeding arteries visibly slowed flow through the arteriovenous fistula and produced more normal flow to the surrounding brain. Surgery was well tolerated and did not produce any neurological deficits. A postoperative conventional angiogram demonstrated decreased shunt flow through the lesion, and the patient underwent stereotactically focused irradiation of the AVM uneventfully. Follow-up angiography has not yet been obtained.

Activation PET Scanning. The patient underwent PET scanning 7 days before craniotomy. The surgeon was not informed of the results. Initial (baseline) non-invasive functional brain mapping was performed by measuring normalized regional cerebral blood flow using the intravenous oxygen-15 (¹⁵O) water bolus technique^{5,10} and the PC-2048B PET scanner* with in-plane and axial spatial resolutions of 5- to 6-mm full width at half maximum. Fifteen slices with a center-to-center distance of 6.8 mm were simultaneously imaged and a rotating germanium-68 source was used to correct the images for attenuation of the gamma rays in the skull and brain tissue. The image planes were chosen parallel to the patient's inferior orbitomeatal (OM) line and the head was firmly immobilized by means of a customized holder consisting of a rapidly hardening self-inflating foamlike material. The OM line was aligned with the tomograph's laser reference line which was transcribed onto the head-holder as a marker for the correlation of PET and MR imaging. An intravenous catheter was placed into the left brachial vein for tracer injection. A dose of 40 mCi of ¹⁵O-labeled water was administered and data were collected over 1 minute. The patient's eyes were closed and covered, the ears were plugged, surrounding noise was subdued, and the room lights were dimmed. The scanning procedure was performed twice, first in a baseline setting where the patient was simply lying quietly on a couch.

During the second study (activation state), the patient's right hand was stimulated by moving a vibrator

* Positron emission tomograph scanner manufactured by Scanditronix AB, Uppsala, Sweden.

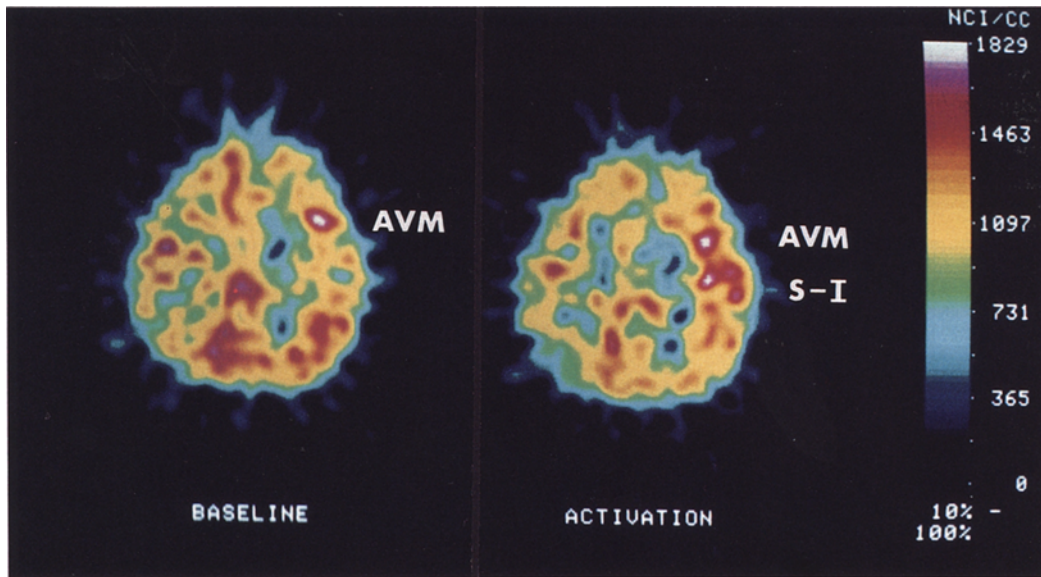


FIG. 2. *Left:* A $H_2^{15}O$ positron emission tomography (PET) scan performed in the resting (baseline) state demonstrating the arteriovenous malformation (AVM). *Right:* A PET scan performed during vibrotactile stimulation of the fingers (activation) demonstrating both the AVM and the increased radioactivity in the postcentral hand area (S-I), confirming localization of the AVM to the precentral gyrus immediately in front of it. NCI/cc = nanoCuries/cubic centimeter of tissue.

(frequency 110 Hz, amplitude 2 mm)† across the finger tips at a rate of one sweep per second starting 30 seconds prior to tracer injection. No arterial blood sampling was required for this application since relative changes in cerebral blood flow between the baseline and activation states were of interest only.⁴ An MR image was obtained at the same 15 planes as the PET studies. Slice registration was ensured using a thin $CuSO_4$ -filled (5 mm) catheter attached to the side of the customized headrest, and visible in an MR image, coincident with the reference line identifying the PET scan reference plane.² The PET scans were analyzed by a physiologist-imager who was unaware of the location of the AVM and of the operative findings.

The baseline PET scan identified an area of increased radioactivity in the left frontal region, corresponding to the AVM (Fig. 2). The activation PET scan, performed during vibrotactile stimulation of the fingers of the right hand, demonstrated the AVM as seen on the baseline PET scan and an area of increased radioactivity behind the AVM corresponding to increased blood flow in the postcentral somatosensory region of the right hand (Fig. 2). Thus, PET scanning in the activation phase produced results identical to intraoperative inspection, angiography, and cortical mapping: it localized the AVM to the precentral hand region by demonstrating it to reside immediately in front of the

activated region corresponding to the postcentral somatosensory hand area. Computer analysis of the PET images further corroborated this initial visual analysis by demonstrating a right-left asymmetry of radioactivity during vibrotactile stimulation of the hand, thus confirming activation of the left somatosensory hand region. Two peaks of radioactivity were identified in the left hemisphere, the anterior one corresponding to the AVM and the posterior one corresponding to the somatosensory hand region, confirming the relationship of the AVM to the pre- and postcentral gyri as established at surgery (Figs. 3 and 4).

Discussion

The treatment of cerebral AVM's remains controversial, especially as it applies to unruptured lesions in eloquent areas. The availability of alternatives to surgery, such as stereotactically focused radiotherapy, make identification of the relationship of AVM's to functionally important ambient brain regions all the more actual. Nonphysiological imaging modalities such as MR imaging and CT scanning can illustrate the relationship of AVM's to recognizable anatomical structures such as the basal ganglia, thalamus, and internal capsule, but cannot identify somatosensory regions.^{6,7} This is readily accomplished by PET scanning, which is also well suited for the study of AVM's.⁸ Arteriovenous malformations are ideal lesions to assess in this combined fashion because they are diagnosed preoperatively and are readily apparent on PET scanning; in addition, if they have not recently bled, they

† Vibrator, Model 91, manufactured by Daito, Osaka, Japan.

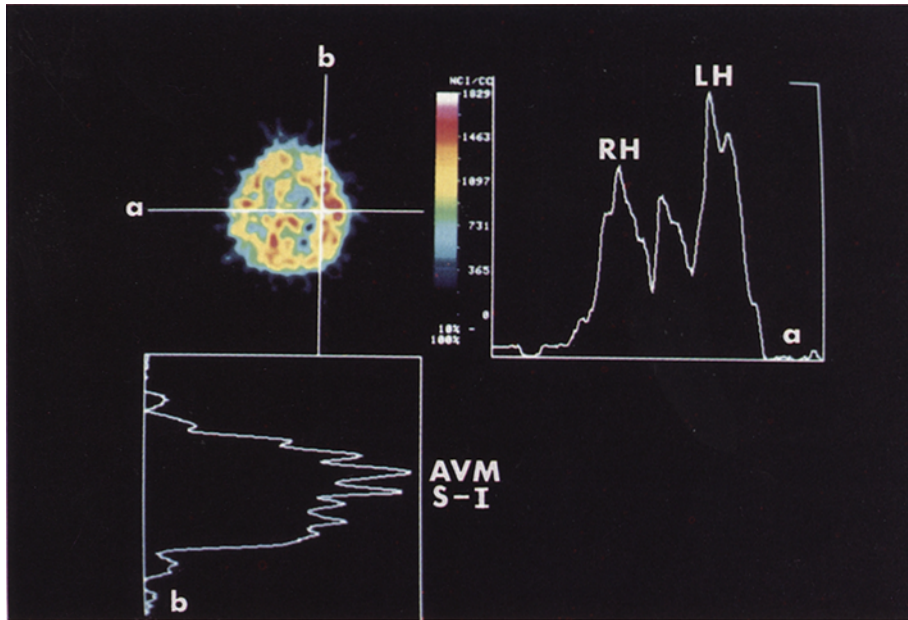


FIG. 3. Profiles across a tissue-activity positron emission tomography image in a transaxial plane at the level of the hand sensorimotor region during vibrotactile stimulation of the fingers of the patient's right hand. The horizontal profile (a) shows asymmetry due to activation of the left somatosensory hand area; the vertical profile (b) shows two prominent peaks originating from the arteriovenous malformation (AVM) in the precentral gyrus and the activated somatosensory hand area (S-I), in the postcentral gyrus. RH = right hemisphere; LH = left hemisphere. NCI/cc = nanoCuries/cubic centimeter of tissue.

do not cause cerebral edema or structural distortions (as do gliomas or other tumors) which could distort functionally important regions or mask their activation pattern by confounding background activity.

The technique of activation PET scanning has, so

far, largely been used for physiological and neuropsychological investigation of normal volunteers, without direct anatomical and physiological corroboration.^{4,9,11} This is the first report to confirm the findings of functional PET scanning by intraoperative cortical map-

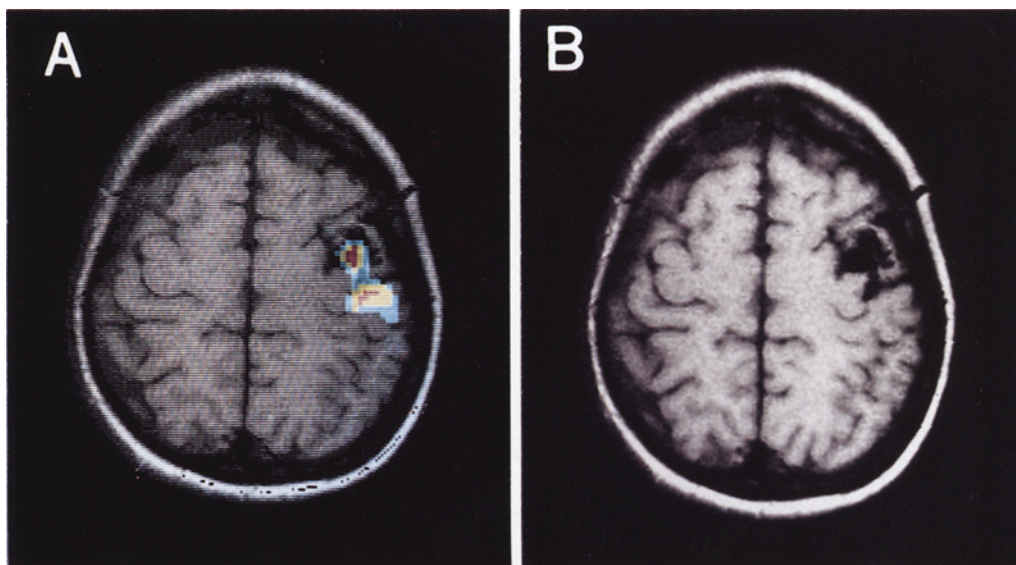


FIG. 4. A: Superposition of a matched magnetic resonance (MR) image and a positron emission tomography-cerebral blood flow image. This figure shows the increased relative cerebral blood flow in the postcentral hand area due to vibrotactile stimulation, and the increased radioactivity in the region of the arteriovenous malformation in front of it, confirming its localization to the precentral gyrus. B: Preoperative MR image alone.

Functional PET scanning

ping, thus validating the technique of activation PET scanning. This case also represents the first instance where functional PET scanning was used to assess the relationship of a structural lesion to eloquent cortex. The relationship demonstrated by functional PET scanning was confirmed at surgery by cortical mapping, validating this technique for the assessment of patients who harbor such lesions. Functional PET scanning is now part of our treatment protocol. We have found it a useful factor to take into consideration in cases with similar pathologies and structure-function relationships, when considering resection or stereotactically focused radiotherapy as the primary mode of treatment.

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