

Neurological Research

A Journal of Progress in Neurosurgery, Neurology and Neurosciences

ISSN: 0161-6412 (Print) 1743-1328 (Online) Journal homepage: <http://www.tandfonline.com/loi/yner20>

[¹⁵O]-water PET and intraoperative brain mapping: A comparison in the localization of eloquent cortex

Federico Viñas, Lucia Zamorano, Ralph-Axel Mueller, Zhaowei Jiang, Harry Chugani, Darren Fuerst, Otto Muzik, Thomas Mangner & Fernando Diaz

To cite this article: Federico Viñas, Lucia Zamorano, Ralph-Axel Mueller, Zhaowei Jiang, Harry Chugani, Darren Fuerst, Otto Muzik, Thomas Mangner & Fernando Diaz (1997) [¹⁵O]-water PET and intraoperative brain mapping: A comparison in the localization of eloquent cortex, *Neurological Research*, 19:6, 601-608, DOI: [10.1080/01616412.1997.11740867](https://doi.org/10.1080/01616412.1997.11740867)

To link to this article: <http://dx.doi.org/10.1080/01616412.1997.11740867>



Published online: 20 Jul 2016.



Submit your article to this journal 



Article views: 2



View related articles 



Citing articles: 2 View citing articles 

Full Terms & Conditions of access and use can be found at
<http://www.tandfonline.com/action/journalInformation?journalCode=yner20>

[¹⁵O]-water PET and intraoperative brain mapping: A comparison in the localization of eloquent cortex

Federico C. Viñas, Lucia Zamorano, Ralph-Axel Mueller*, Zhaowei Jiang, Harry Chugani*, Darren Fuerst, Otto Muzik*, Thomas J. Mangner* and Fernando G. Diaz

Department of Neurosurgery, *PET Center, Children's Hospital, Wayne State University, Detroit, MI, USA

[¹⁵O]-water PET was performed on 12 patients with structural lesions for localization of the motor (n=5), language (receptive and expressive; n=6), and visual cortex (n=1). All these patients underwent interactive image-guided surgery using an infrared digitizer and intraoperative electrical stimulation mapping for motor, sensory, language, and visual cortex location. MRI-PET coregistration was performed using a surface matching approach that integrated functional information with interactive image guidance during the surgical procedure. An awake craniotomy with motor and sensory intraoperative stimulation was performed using a registered bipolar electrode that was tracked on real-time during the surgical procedure. Intraoperative functional findings were displayed and saved on the registered MRI images. The sites of functional PET activation during the performance of motor, visual and language tasks were then compared to the results of intraoperative cortical stimulation in 11 patients and visual evoked potentials in one. The results of the PET activation studies were concordant with the findings of intraoperative stimulation in all cases. During resection of the structural lesions, intraoperative stimulation was continued in the subcortical pathways, and five patients had positive responses on areas not identified by the functional PET. Furthermore, 3 patients showed transitory changes in function (speech arrest 1, naming difficulty 1, and motor weakness 1) that were reversible after changing the dissection technique or a brain retractor. [¹⁵O]-water PET was reliable in identifying the motor, visual, and language cortex. Language-related rCBF increases were highly distributive, although only part of these activations were subjected to intraoperative stimulation. We conclude that [¹⁵O]-water PET can be used for preoperative noninvasive identification of functional cortex and may be useful in neurosurgical preplanning. Intraoperative mapping still remains the main means to avoid neurological damage as it can be performed during the entire surgical procedure to avoid damage to cortex, pathways, and damage secondary to ischemia or edema (brain retraction). [Neurol Res 1997; 19: 601-608]

Keywords: Eloquent cortex; functional mapping; intraoperative localization; water PET

INTRODUCTION

Neurosurgical procedures rely on precise delineation of the relation between structure and function in the central nervous system. Techniques for image-guided localization are frequently being used in the surgical management of a variety of intracranial lesions including brain tumors, arteriovenous malformations, and those found in epilepsy patients¹⁻³. Functional localization is also necessary for neurosurgical procedures near or involving eloquent cortical regions. For this group of patients, intraoperative localization can be performed either anatomically (by visual identification of anatomical landmarks) or by registered intraoperative electrical stimulation (intraoperative functional mapping). [¹⁵O]-water positron emission tomography is a technique that provides noninvasive localization of cortical function, in terms of task-related regional cerebral blood flow (rCBF)

changes. The present study attempts to validate the findings of [¹⁵O]-water positron emission tomography (¹⁵O)-water PET) comparing its accuracy and clinical usefulness with more traditional techniques, such as the registered intraoperative mapping. Special emphasis was given to evaluate intraoperative usefulness to improve neurological outcome in patients with lesions in or around eloquent cortex.

MATERIALS AND METHODS

Patient population

During the period January to September 1996, at Wayne State University, 18 patients with structural lesions requiring surgical resection underwent a preoperative [¹⁵O]-water PET scan for localization of the motor (n=14), language (n=15), and visual cortex (n=1). Subsequently, they underwent an image-guided craniotomy and registered intraoperative electrical stimulation (functional mapping) and surgical resection of their intracranial lesions. In our patient group there were 6

Correspondence and reprint requests to: Lucia Zamorano MD, Dr Med, Department of Neurosurgery, Wayne State University, 4160 John R Suite 930, Detroit, MI 48201, USA. Accepted for publication August 1997.

women and 12 men. Ages ranged from 8 years to 74 years; mean age was 36.3 years. Eleven patients had brain tumors, while one patient had a cerebral arteriovenous malformation (AVM). The results obtained by $[^{15}\text{O}]$ -water PET scan were then compared with the results of intraoperative functional mapping.

Methodology

Each patient underwent FDG PET and $[^{15}\text{O}]$ -water PET scans prior to surgery. The day of surgery they underwent MRI that was registered with the PET scan using surface matching techniques. Functional volumes defined by the PET scan were transferred to the MRI images. The patients underwent awake craniotomy, and interactive image localization was done using an infrared-based system. During surgery each patient underwent intraoperative functional mapping, the results of which were compared with the positive findings obtained from the preoperative PET scan.

$[^{15}\text{O}]$ -water PET scan

The $[^{15}\text{O}]$ -water PET technique measures regional cerebral blood flow (rCBF) associated with neural activation in response to sensory stimulation or cognitive tasks^{4,5}. $[^{15}\text{O}]$ -water PET was performed using a Siemens EXACT HR positron scanner (Knoxville, TN, USA) with an axial field-of-view of 15 cm. The reconstructed image resolution obtained in the study was 5.5 ± 0.35 mm at full-width at half maximum (FWHM) in-plane and 6.0 ± 0.49 mm FWHM in axial direction (reconstruction parameters: Shepp filter with 0.3 cycles/pixel cutoff frequency). A 'scout scan' was performed for determination of delay between injection in the antecubital vein and tracer arrival in the brain. The isotope dose for this scan was 5 mCi. An external ^{68}Ga line source transmission scan was performed for attenuation correction.

The dose for each activation scan was 25 mCi in adult patients. In children, the dose was $0.357 \text{ mCi kg}^{-1}$ of the patient's weight⁶. The $[^{15}\text{O}]$ -water dose diluted in 6 ml of normal saline was administered as a slow bolus over 20 sec, using a volumetric pump via a peripheral intravenous line. A static 60 sec scan acquisition was initiated after the delay determined in the scout scan. The stimulation/task window was 50 sec, starting 20 sec before the PET scan. A minimum of 10 min was allowed between scans for decay of ^{15}O (physical half-life 123 sec). A maximum of 5 experimental conditions was selected for each patient according to lesion location. Each selected condition was scanned twice in each patient, with counterbalanced order of repeat scans.

For each patient, a selection was made according to lesion localization from the following set of experimental conditions:

1. Resting (with eyes closed and covered).
2. Opposing finger-thumb movement of right/left hand: Patient sequentially taps thumb with fingers of right/left hand.

3. Listening to 10 short sentences (e.g., 'The game was very interesting', 'He'll be back in three hours') played through earphones from an analogue tape recorder. Each sentence was presented over c. 2 sec followed by a 3 sec interval.
4. Listening and immediate repetition of 8 sentences of similar type as used for condition 2. Inter-stimulus interval in this condition was slightly longer to allow time for repetition.
5. Stimulation of the right/left visual half-field by means of simple geometric objects displayed on the right/left of a fixation cross on a computer monitor, which is positioned in the patient's field of view.

PET data analysis

For each scan, 47 transaxial image planes were reconstructed, each containing 128×128 pixels, with a pixel size of 1.73×1.73 mm and a plane separation of 3.125 mm. The volume was analyzed using the automated PET activation analysis package by Minoshima *et al.*^{7,8}. The algorithm performs an intra-subject motion correction (image coregistration), pixel normalization, pixel-by-pixel subtraction between image sets (control and stimulation), and a peak activation analysis, which provides stereotactic Talairach coordinates⁹, mean rCBF increase, z-score, and *p*-value for any given peak of rCBF increase. Statistical assessment is based on smoothness estimation¹⁰ and a pooled-variance *t*(*Z*)-statistic model¹¹. Subtractions serve to identify components of rCBF changes associated with experimental task conditions. The following subtractions were performed, according to selection of experimental condition:

- Movement of the right/left hand minus resting
- Listening to sentences minus resting ('language perception')
- Repeating sentences minus listening ('language production')
- Stimulation of right/left visual half-field minus resting.

MRI-PET coregistration

In an effort to acquire correlated information about a patient's brain, volumes generated from different image modalities were matched to each other in Cartesian space. Current existing correlation techniques include point-point matching, surface matching, and volume matching. Since all our patients had their CTs and MRIs done on the same day of the surgery, matching between CT and MRI was performed with implanted fiducial markers, using the point-point matching scheme. Since all patients had their PET studies done days before the surgery date, we used surface matching techniques, implementing JhR's algorithm¹² in the Neurosurgical Planning System (NSPS) software. Initially, segmentation methods were used to segment brain volume out of both MRI and PET images. Brain surface images were generated from these segmented brain volumes. Then an automated algorithm was employed to align two

surfaces together in a three-dimensional (3-D) Cartesian space. The criteria for our alignment was to minimize the distance between two surfaces. The transformation matrix is then calculated as soon as minimum distances are reached. To increase the speed of this automatic alignment process, a distance volume called chamfer distance volume was created prior to the matching. The average accuracy of the surface matching methods is around 2.5–3.6 mm.

Intraoperative interactive image localization

Intraoperative interactive localization was done using an infrared detecting system developed at Wayne State University, using a 3-D opto-electronic motion analysis system (Optotrak 3-D Bar, Northern Digital, Waterloo, Canada) that uses light-emitting diodes (LEDs). Details of this system have been presented elsewhere^{13–15}. Three infrared sensors track target points defined by several miniature LEDs placed in the surgeon's instrument, in a predefined relationship referred to as a 'pointer'. Another device with several infrared emitters on it is attached to the patient's head and then mounted into the head holder or stereotactic frame ('dynamic body reference'). The dynamic body reference indicates the patient's position in relation to other LEDs, while the pointer indicates the position of the surgical instrument. With this information the system can combine the virtual patient and virtual instrument information and transmit it to the neurosurgeon. Each time the surgeon moves the instrument, three monitors mounted in the room display the instrument position on the pre-acquired computer-generated images.

The surgical procedure starts by mapping the image studies with the intraoperative space (intraoperative registration). This is achieved by touching the pointer on at least three or four 'real' points that can be easily located in the pre-acquired images. We use known points of the stereotactic frame or fiducial markers. Once this is accomplished, any time the pointer is used, its tip position and trajectory are simultaneously displayed on the computer images, giving real-time orientation. For our patients the display was on their MRI images with the volumes of interest of functional areas defined by a $[^{15}\text{O}]$ -water PET scan.

Registered intraoperative electrical stimulation

The registered intraoperative electrical stimulation involved both cortical and subcortical intraoperative mapping of motor, sensory, and language functions. Patients were positioned in the supine, semilateral, or lateral position according to the location of the lesion and surgeon's preference, and underwent an awake, centered craniotomy. Propofol anesthesia was then induced intravenously, and a local anesthetic field block was placed, using a mixture of equal volumes of 0.5 percent lidocaine and 0.25 percent bupivacaine (Marcaine), both with 1:100,000 epinephrine¹⁶. This block was performed around the entire area of the planned incision. The scalp incision and centered

craniotomy were then performed in the usual manner, according to the surgical preplanning protocol. During the surgical exposure, the infrared probe was used at all times to confirm the entry point, trajectory, and target localization. Before opening the dura, patients were awakened by interruption of the propofol administration. Upon exposure of the cerebral cortex, a modified bipolar probe (Neuro N50, Fischer, Freiburg, Germany) adapted with LEDs was brought to the surgical field, for registered stimulation of language, motor, and sensory functions. All patients were awake and conversant within 6–10 min of stopping the propofol.

Initially, anatomical localization was performed by touching the surface of the brain with the infrared digitizer. Each time that the pointer touched the cerebral cortex, the position of the instrument was simultaneously displayed on the MRI/PET image-reconstructions in axial, coronal, and sagittal planes.

Functional localization was performed by applying an electric current to the cortical surface with the N-50 modified bipolar instrument. When searching for the primary motor cortex, stimulation was started with a frequency of 2–50 Hertz, pulses of 0.5–1 msec, and a current as low as 2 MA and usually up to 5–7 MA. When searching for sensory cortex or language, stimulation was initiated with the same settings, but the current was increased to 10–15 MA. Mapping and monitoring neurological function were continued in cortical and subcortical areas throughout the surgical procedure. A neuropsychologist was present in the operating room in all cases to assess motor, sensory, visual, and language functions during the mapping, and throughout the surgical procedure.

Language functions were evaluated with standard stimuli and methods used by neurologists and neuropsychologists for the clinical assessment of aphasia. The evaluation included tests of receptive language (comprehension), repetition, and expressive language (fluency). As visual stimuli could not be presented to many patients due to position and draping, the language evaluation used auditory stimuli only. Immediately prior to electrical stimulation mapping, a thorough baseline evaluation was completed, against which performance during stimulation could be judged. As the language tasks and stimuli that were used are relatively simple and are performed perfectly by normal adults, any dysfluency, arrest, or error (i.e. paraphasic, perseverative, or inappropriate response) during stimulation mapping was considered significant. When a site tested positive, stimulation was removed until speech returned to baseline, and then retested at least once to confirm the result.

Motor functions were mapped by exposing and observing the appropriate side of the patient's body, watching for involuntary muscle activity at the same frequency as the electrical stimulation. Somatosensory functions were mapped using patient self-report of somatosensory phenomena. As with language testing, sites positive for somatosensory function were retested at least once to confirm the reliability of the patient's self-report.

Visual evoked potentials are performed by presenting the patient a checkerboard pattern of black and white squares, and analyzing the occipital signal following the pattern reversal.

Continuous intraoperative language monitoring was performed in the same fashion as during stimulation mapping. Again, as the tasks used for testing were relatively simple ones usually performed perfectly by intact adults, any change from baseline performance was considered significant. Continuous monitoring of motor functions was done using those aspects of the standard neurological motor examination that could be adapted to each patient's position, restraints, and drapes. Grip strength was also tested using a hand dynamometer. Generally, patients were able to tolerate continuous motor evaluation for periods up to 2 h without signs of significant fatigue. Any noticeable change in strength (or, in the case of grip strength, a decline greater than 20% from the baseline measurement) was considered significant.

Correlation between $[^{15}\text{O}]$ -water PET and registered intraoperative electrical stimulation

Prior to the surgical procedure, the PET subtraction images for motor, visual, and language tasks had been superimposed onto the co-registered MRI images. Upon completion of the registered intraoperative electrical stimulation, the silhouettes corresponding to areas of eloquent cortex (recognized by registered intraoperative stimulation on 11 patients and visual evoked potentials in one), were saved as bi-dimensional coordinates, for a subsequent comparison with the bi-dimensional coordinates of the eloquent regions determined by $[^{15}\text{O}]$ -water PET.

Stereotactic coordinates determined by the registered intraoperative electrical stimulations were transferred as volumes into the co-registered MRI/PET images. The fusion of images obtained by $[^{15}\text{O}]$ -water PET and registered intraoperative electrical stimulation onto the MRI-based computer reconstructions allowed us to perform a visual comparison within and between volumes determined by $[^{15}\text{O}]$ -water PET and by registered intraoperative electrical stimulation, with a resolution of a few millimeters.

RESULTS

During the localization of motor function ($n=5$), the findings of the $[^{15}\text{O}]$ -water PET motor activation studies were concordant with the findings of intraoperative cortical stimulation in all patients. The intraoperative stimulation was continued in the subcortical pathways, and during tumor resection. During the stimulation of subcortical areas, three patients had positive responses, manifested by movement of an extremity when the subcortical fibers were electrically stimulated. Since $[^{15}\text{O}]$ -water PET primarily assesses blood flow changes on gray matter, these eloquent subcortical white matter fibers were not seen in the PET/MRI co-registered images.

During the localization for language ($n=15$), a centered craniotomy was performed. This limited surgical approach did not expose all language areas identified preoperatively by the $[^{15}\text{O}]$ -water PET studies. There was, however, a concordance between eloquent exposed cortex and PET. Additionally, while performing the registered electrical stimulation we investigated areas considered silent by the PET activation studies. Although we did not find any cortical functional area not detected by PET, during the stimulation of subcortical areas, two of the 12 patients had a temporary dysphasia, associated with the stimulation of subcortical fibers.

In patient number 18 (Table 1), who had a tumor located close to the primary visual cortex, there was a concordance between the region identified by the $[^{15}\text{O}]$ -water PET visual activation studies and the visual evoked potentials.

During the resection of structural lesions, three patients showed transitory changes in function, manifested by speech arrest in one patient, naming difficulty in another, and extremity motor weakness in a third patient, which were reversed upon temporary cessation of the tumor resection in two patients; or repositioning of the brain retractors in the third.

Representative cases

Case 1

A 33 year-old right-handed woman presented with a 2 month history of new-onset partial seizures involving the right-upper extremity. Her initial work-up included a CT scan and MRI which revealed an anterior left temporal mass. The neurological exam was significant for a small visual field defect, and minimal dysarthria. Before the surgical procedure, the patient underwent a $[^{15}\text{O}]$ -water PET for the localization of the expressive and receptive language cortex (Figure 1). The tumor was found to be located immediately behind the receptive language cortex. She underwent an awake centered craniotomy with registered intraoperative electrical stimulation. Upon superimposition of the results, there was concordance between the exposed language area and the results of $[^{15}\text{O}]$ -water PET. The tumor was resected through a small corticotomy in front of the language cortex. Her post-operative course was unremarkable and she was discharged home without new neurological deficits. The pathology was consistent with anaplastic astrocytoma (patient 7).

Case 2

A 30 year-old right-handed woman with generalized tonic-clonic seizures was referred from an outside institution. Her MRI demonstrated a right posterior frontal mass, located in the neighborhood of the motor cortex. The neurological exam revealed no deficits. Before the surgical procedure, a $[^{15}\text{O}]$ -water PET was performed with motor activation of the left foot (Figure 2). The motor cortex corresponding to the left foot was found to be located just behind the mass. During the surgical procedure, findings on the registered intra-

Table 1: Clinical information of 18 patients

	Age/sex	Side	Location (FDG PET)	Etiology	Tasks	Intraoperative
1	31 M	Left	Frontal	Oligoastrocytoma	MLR	RES
2	61 M	Left	Post. Parietal		MLR	RES
3	40 M	Left	Parietal	Anaplastic astrocytoma	LR	RES
4	54 M	Right	Frontal	Astrocytoma grade II	M	RES
5	56 M	Left	Frontal	Anaplastic astrocytoma	MLR	RES
6	74 M	Right	Frontotemporal	Glioblastoma multiforme	MLR	RES
7	33 M	Left	Temporal	Epilepsy	LRGVr	RES
8	41 M	Left	Fronto-temporoparietal	Anaplastic astrocytoma	MLR	RES
9	33 F	Left	Temporal	Anaplastic astrocytoma	LR	RES
10	53 M	Left	Frontoparietal	Anaplastic astrocytoma	MLR	RES
11	30 F	Right	Ant. cingulate	Oligodendrogioma	M	RES
12	47 F	Bilat.	Left parietal Right temporal	Glioblastoma multiforme	MLR	RES
13	22 F	Left	Frontotemporal	AVM	MLR	RES
14	8 M	Left	Diffuse	Epilepsy	MLR	RES
15	16 F	Bilat.	Diffuse	Epilepsy	VHF	VEP?
16	20 M	Right	Diffuse	Epilepsy	MLR	RES
17	20 M	Left	Diffuse	Epilepsy	MLR	RES
18	16 F	Right	Diffuse	Epilepsy	MLP	RES

Ant, anterior; AVM, arteriovenous malformation; E, encoding verbal stimuli; L, listening to sentences; M, motor; Post, posterior; R, repeating sentences; RES, registered electrical stimulation; VEP, visual evoked potentials; VHF, visual half field stimulation method; Vr, visual recall

operative electrical stimulation were superimposed with the ¹⁵O]-water PET scan, and found to be concordant. The tumor was resected and the patient was discharged home without neurological deficits. The pathology was consistent with oligodendrogioma (patient 11).

DISCUSSION

When planning the resection of cortical and subcortical structural lesions, the identification location of eloquent areas of the brain is critical¹. Recent technological developments in surgical techniques and neuroimaging such as interactive image-guided surgical procedures have opened new frontiers in the surgical treatment of neurosurgical patients. It is possible to localize pre-operatively anatomically structural lesions. By noninvasive means, speech, motor, sensory, and visual areas of the brain can be recognized. However, it is necessary to superimpose this functional information into the anatomical image, and the usefulness of this technique needs to be validated.

During most intracranial procedures, eloquent cortical areas can be either anatomically or functionally identified. A frequent problem encountered during conventional anatomical localization is that anatomical landmarks (i.e. Rolandic area) are difficult to discern through the intact pia. Furthermore, in many cases the normal anatomy is distorted or displaced by edema or tumors¹⁷. Even with the use of interactive image guidance it is not possible to define the functional areas.

In addition, there is a significant variability in the location of language areas among individuals that can result in post-operative deficit for some.

Hemodynamic imaging methods (¹⁵O]-water PET, fMRI), although still limited to large research centers, are becoming more accepted for functional imaging studies. Activation PET studies using intravenously administered ¹⁵O]-water as the diffusible blood-flow tracer, is a noninvasive approach for the mapping of higher brain functions in humans¹⁸. The technique is, however, extremely expensive and not readily available in most centers. Relatively few studies have compared the reliability of hemodynamic techniques with the intraoperative registered electrical stimulation; most validation studies were based on functional MRI, and describe its usefulness for the determination of motor and language areas¹⁹. Other studies reported concordance between findings of functional MRI and ¹⁵O]-water PET²⁰⁻²².

The technique for cortical stimulation and mapping of language was initially developed by Penfield in 1959, for the surgical treatment of patients with epilepsy²³. Since Penfield's original description, several modifications have been added to the technique^{17,24}. Previous studies have demonstrated that during bipolar cortical stimulation, electrical neuronal changes are confined to a few millimeters of cortex between the electrodes^{25,26}. Most centers perform functional mapping only in the cerebral cortex, prior to tumor resection. On the other hand, in the present study, the registered intraoperative

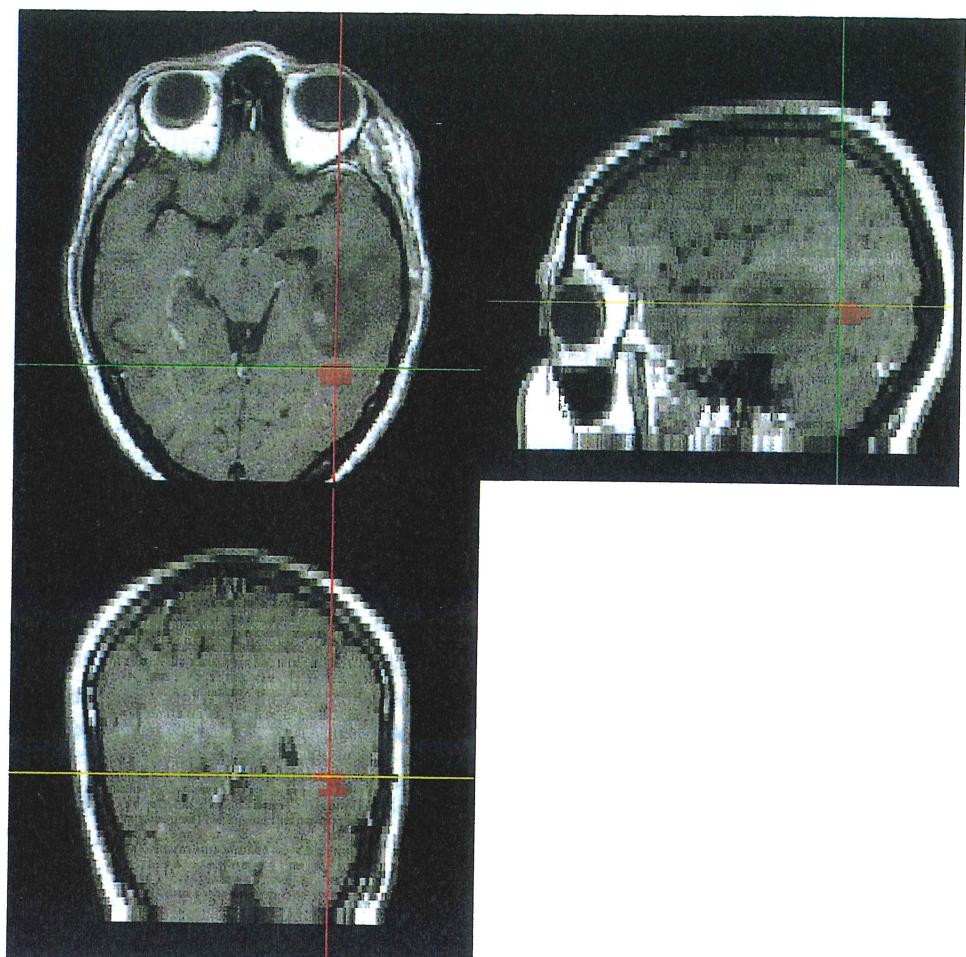


Figure 1: Localization of receptive language. Simultaneous overlay of the receptive language findings obtained by $[^{15}\text{O}]$ -water PET onto the T-1 $[^{15}\text{O}]$ -water PET. The receptive language was mapped while the patient was listening to sentences, and was found to be located behind the hypointense region. This was thereafter confirmed by the registered intraoperative electrical stimulation. In this patient, the localization of the receptive speech cortex allowed the resection of the tumor without new neurological deficits (patient 7)

electrical stimulation was performed in both cortical and subcortical areas, before and through the duration of the resection, in order to increase the safety of this type of procedure. The stimulation of the subcortical pathways allows us to identify and preserve 'eloquent tracts', and to prevent neurological deficits. For the same reasons, continuous monitoring of functions are performed through the surgical procedure.

$[^{15}\text{O}]$ -water activation PET is useful only for gray matter localization (cerebral cortex and basal ganglia), where significant changes in blood flow are related to specific tasks. When functional mapping is performed only in the cerebral cortex, findings are consistent with those of the $[^{15}\text{O}]$ -water PET activation studies. However, we found registered intraoperative electrical stimulation to be a more valuable tool for surgical procedures, since it allowed us to identify subcortical eloquent pathways, in addition to eloquent cortex. Continuous subcortical functional mapping during the tumor resection allowed us to prevent permanent deficits in three of our patients, who developed transitory changes in function. The neurosurgeon should

be aware of these important 'eloquent tracts' rather than rely only on the preoperative cortical localization.

Advances in imaging techniques have created the need for more precise navigational assistance to approach image-defined lesions. The coupling of interactive image-guidance with registered intraoperative electrical stimulation allows for optimization of surgical procedures, maximizing the extent of resection and reducing the onset of neurological deficits.

CONCLUSION

$[^{15}\text{O}]$ -water PET is useful in identifying the motor, visual, and language cortex, as identified by the intraoperative registered electrical stimulation. This technique is applicable to resection of any lesion located close to eloquent areas, including resection for intrinsic brain tumors and vascular arteriovenous malformations, in which the goal is to maximize the extent of the resection with minimal risk of motor, sensory, or speech deficits. Language-related rCBF increases were highly distributive, and only some of this activation-foci were

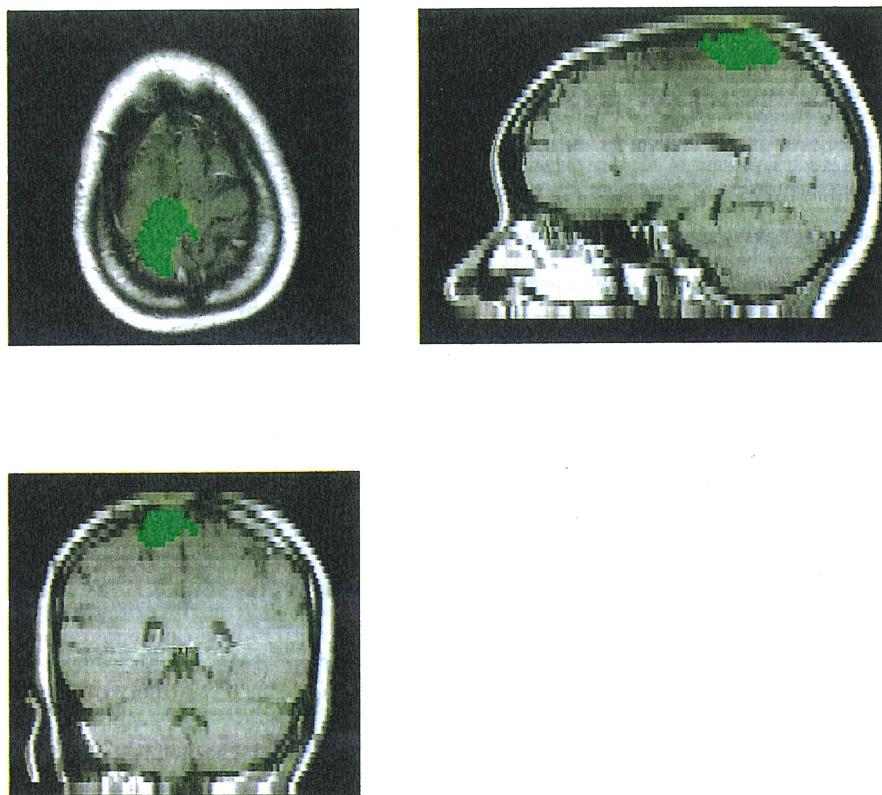


Figure 2: Localization of the motor cortex. Simultaneous display of the $[^{15}\text{O}]$ -water PET results upon left foot activation onto the axial, sagittal, and coronal MRI reconstructions. The green area represents the motor cortex activated during movements of the left foot. This area was concordant with the results of the registered intraoperative electrical stimulation. The tumor was resected and the patient discharged without neurological deficits (patient 11)

subjected to intraoperative stimulation. Further study is necessary to evaluate visual function. $[^{15}\text{O}]$ -water PET can be used for preoperative noninvasive identification of functional cortex, may be useful in neurosurgical preplanning, and also during the planning of radiosurgical and other noninvasive procedures.

We believe that registered intraoperative electrical stimulation (intraoperative functional mapping) still remains the primary means to avoid neurological damage during the resection of lesions close to or around eloquent regions, as it can be performed during the entire surgical procedure to avoid damage to cortex and subcortical pathways. As the procedure is performed under local anesthesia, continuous function monitoring may prevent damage secondary to ischemia or edema (brain retraction).

REFERENCES

- 1 Morris GL, Mueller WM, Yetkin FZ, Haughton VM, Hammecke TA, Swanson S, Rao SM, Jesmanowics A, Estkowski LD, Bandettini PA, Wong EC, Hyde JS. Functional Magnetic Resonance imaging in partial epilepsy. *Epilepsia* 1994; **35**: 1194-1198
- 2 Hacker H, Khorram-Sefat D, Herminghaus S. Presurgical fMRI of Language Lateralization in patients with left hemispheric lesions. *Neuroimage* 1996; **3**: s439
- 3 Fox PT, Raichle ME, Mintun MA, Dence C. Nonoxidative glucose consumption during focal physiologic neural activity. *Science* 1988; **241**: 462-464
- 4 Chertkow H, Bub D. Functional activation and cognition: The ^{15}O PET subtraction method. In: Kertesz A, ed. *Localization and Neuroimaging in Neuropsychology*. San Diego: Academic Press, 1994: pp. 151-184
- 5 Frahm J, Krüger G, Merboldt K-D, Kleinschmidt A. Dynamic uncoupling and recoupling of perfusion and oxidative metabolism during focal brain activation in man. *Magn Reson Med* 1996; **35**: 143-148
- 6 Shore RM, Hendee WR. Radiopharmaceutical dosage selection for pediatric nuclear medicine. *J Nucl Med* 1986; **27**: 287-298
- 7 Minoshima S, Koeppe RA, Fessler JA, et al. Integrated and automated data analysis method for neuronal activation studies using ^{15}O -water PET. In: Uemura K, ed. *Quantification of Brain Function*. Amsterdam: Elsevier, 1993: pp. 409-415
- 8 Worsley RP, Mazziotta JC, Cherry SR. MRI-PET registration with automated algorithm. *J Comput Ass Tomogr* 1993; **17**: 536-546
- 9 Talairach J, Tournoux P. *Co-Planar Stereotaxic Atlas of the Human Brain*. Stuttgart: Georg Thieme, 1988
- 10 Friston KJ, Frith CD, Liddle PF, Frackowiak RSJ. Comparing functional (PET) images: The assessment of significant change. *J Cereb Blood Flow Metab* 1991; **11**: 690-699
- 11 Worsley KJ, Evans AC, Marrett S, Neelin P. A three-dimensional statistical analysis of CBF activation studies in human brain. *J Cereb Blood Flow Metab* 1992; **12**: 900-918
- 12 Jiang H, Holton K, Robb R. Image registration of multimodality 3-D medical images by chamfer matching. In: *Proc SPIE Biomed Image Process Three Dimensional Microscopy*, 1992; **1660**: 356-366
- 13 Viñas FC, Zamorano L, Lis-Planells M, Buciuc R, Diaz FG. Interactive intraoperative localization during the resection of intraventricular lesions. *Min Invas Neurosurg* 1996; **39**: 65-70
- 14 Zamorano L, Nolte LP, Kadi AM, Jiang Z. Interactive intraoperative localization using an infrared-based system. *Stereotact Funct Neurosurg* 1994; **63**: 84-88

- 15 Zamorano L, Nolte L, Kadi M, Jiang Z. Interactive intraoperative localization using an infrared-based system. *Neuro Res* 1993; **15**: 290–298
- 16 Silbergeld DL, Mueller WM, Ojemann GA, Lettich E. The use of propofol (Diprivan) for awake craniotomies—Technical note. *Surg Neurol* 1993; **38**: 271–272
- 17 Ojemann G, Ojemann J, Lettich E, Berger M. Cortical language localization in left-dominant hemisphere. *J Neurosurg* 1989; **71**: 316–326
- 18 Momose T, Sasaki Y, Nishikawa Y, Katayama S, Sano I, Nakayima T, Ohtake T, Takashiro K. Functional brain studies with H_2^{15}O -PET: Strategies and problems for approaching higher brain functions with H_2^{15}O -PET. *Radiat med* 1991; **9**: 122–126
- 19 Puce A, Constable RT, Luby ML, McCarthy G, Nobre AC, Spencer DD, Gore JC, Allison T. Functional Magnetic resonance imaging of sensory and motor cortex: Comparison with electrophysiological localization. *J Neurosurg* 1995; **83**: 262–270
- 20 Leblanc R, Meyer E, Bub D, Zatorre RJ, Evans AC. Language localization with activation positron emission tomography scanning. *Neurosurgery* 1992; **31**: 369–373
- 21 Senda M, Kanno I, Yonekura Y, Fujita H, Ishii K, Lyshkow H, Oda K, Sadato N, Toyama H. Comparison of anatomical standardization methods regarding the sensorimotor foci localization and between-subject variation using H_2^{15}O PET activation, a three-center collaboration study. *Ann Nucl Med* 1994; **8**: 201–207
- 22 Wessel K, Zeffiro T, Lou JS, Toro C, Hallet M. Regional cerebral blood flow during a self-placed sequential finger opposition task in patients with cerebellar degeneration. *Brain* 1995; **118**: 379–393
- 23 Penfield W, Roberts L. *Speech and Brain Mechanisms*, Princeton: Princeton University Press, 1959: pp. 157–161
- 24 Luders H, Lesser R, Hahn J, et al. Basal temporal language area demonstrated by electrical stimulation. *Neurology* 1986; **35**: 505–510
- 25 Haglund MM, Ojemann GA, Hochman DW. Optical imaging and epileptiform and functional activity in human cerebral cortex. *Nature* 1992; **358**: 668–671
- 26 Haglund MM, Ojemann GA, Blasdel GG. Optical imaging of bipolar cortical stimulation. *J Neurosurg* 1993; **78**: 785–793