Eur. Radiol. 8, 1573–1580 (1998) © Springer-Verlag 1998

Neuroradiology European Radiology

Original article

Functional MRI of the brain: localisation of eloquent cortex in focal brain lesion therapy

S. Dymarkowski[1], S. Sunaert[1], S. Van Oostende[1], P. Van Hecke[1], G. Wilms[1], P. Demaerel[1], B. Nuttin[2], C. Plets[2], G. Marchal[1]

[1] Department of Radiology, University Hospitals, UZ Gasthuisberg, Herestraat 49, B-3000 Leuven, Belgium
[2] Department of Neurosurgery, University Hospitals, UZ Gasthuisberg, Herestraat 49, B-3000 Leuven, Belgium

Received 19 November 1997; Revision received 23 February 1998; Accepted 3 March 1998

Abstract. The aim of this study was to assess the feasibility of functional MRI (fMRI) in a clinical environment on a large patient group, and to evaluate the pretherapeutic value of localisation of eloquent cortex. Forty patients with focal brain lesions of different origin were studied using fMRI. Functional information was obtained using motor, somatosensory, auditory and phonological stimuli depending on the localisation of the lesions. To obtain information about the spatial accuracy of fMRI, the results were compared with postoperative electrocortical stimulation. Two patients with secondary trigeminal neuralgia were scanned using a motor protocol and were implanted with an extradural plate electrode. Imaging was successful in 40 of 42 patients (including the 2 with trigeminal neuralgia). These patients were analysed for strength of activation, the relation of the lesion to activation sites and the presence of mass effect. The correlation between these data and surgical findings provided significant additional clinical information. Functional MRI can be accurately performed in patients with focal brain lesions using a dedicated approach. Functional MRI offers important clinical information as a contribution to a decrease in post-therapeutic morbidity. The accuracy of the technique can be confirmed by other modalities, including invasive cortical electrostimulation.

Key words: Functional imaging – Brain abnormalities – MR studies – Neoplasms – Image correlation

Introduction

Magnetic resonance imaging has become recognised as one of the most sensitive and specific imaging modalities for the diagnosis and follow-up of brain lesions. Although conventional MRI can exquisitely determine the characteristics of normal brain tissue as well as of most focal lesions, its findings are entirely based on anatomy and morphology. Notwithstanding the high sensitivity of MRI for the visualisation of brain lesions, the relationship to functionally important cortex is not clearly established. Knowing that a vast majority of brain lesions undergo surgical treatment, stereotactic biopsy, radiotherapy or endovascular intervention, it may be appropriate to identify function in nearby or involved cortex so that these areas can be spared during therapy.

It has been shown that functional MRI (fMRI) is capable of depicting neuronal activity in primary sensory brain regions, including the visual, sensorimotor, auditory and language cortices [1–4]. Based on a blood-oxygen-level-dependent (BOLD) contrast, fMRI allows visualisation of the haemodynamic response elicited by sensory stimulation or by the execution of specific tasks [5, 7]. As opposed to contrast-bolus MR imaging and positron emission tomography (PET), the performance of fMRI is not constrained by contrast dose or radiation limits. There is increasing evidence that fMRI maps the cerebral cortex accurately, and thus potentially facilitates the assessment of the risk of damaging eloquent brain tissue in therapeutic intervention.

The purpose of this study was to assess the feasibility of fMRI in a clinical environment and to evaluate the value of localisation of eloquent cortex on the pretherapeutic decision making. The accuracy of our fMRI technique was validated with postoperative stimulation in two additional cases.

Materials and methods

Patients

Forty patients (25 males and 15 females; age range 11–71 years, median age 43 years) were studied. They were referred by the departments of neurosurgery or interventional radiology during their pretherapeutic

Correspondence to: P. Van Hecke

workup. All patients had previously undergone conventional CT or MRI investigations. Twenty-nine patients presented with a tumoral lesion, 4 with a cerebral arteriovenous malformation (AVM), 3 with a cavernous angioma, 2 with a haemorrhage, 1 with a migrational disorder causing seizures and 1 with a very large arachnoid cyst. Twenty-four patients displayed symptoms as a result of their illness; 6 others had presented clinical signs but became asymptomatic after steroid therapy. The 10 remaining patients were asymptomatic. Four lesions were incidentally found.

Age and gender of the patients, the nature and localisation of their lesions, their symptoms and subsequent therapy are specified in Table 1. Written informed consent was obtained in all cases prior to the investigation.

In 1 patient who was later reported to be taking drugs, significant brain activation was observed, but since the use of hallucinogenic substances is possibly confounding, this patient was withdrawn from the study.

Two additional patients without focal brain lesions, but with the diagnosis of secondary trigeminal neuralgia, were studied using the same fMRI technique. These patients were implanted with an epidural plate electrode for postoperative electrostimulation.

The correlation between electrostimulation and fMRI in these two cases is discussed separately.

Prior to each examination, the task paradigm was concisely explained to each patient and briefly rehearsed. The importance of immobilisation of the head was stressed and the head was subsequently fixed with foam padding and towels.

Functional MRI activation paradigms

The variety of lesion localisation imposed the use of different activation paradigms. For lesions in the perirolandic area, mainly motor tasks were used. These tasks consisted of finger tapping (sequential opposition of each finger to the thumb), foot extension, tongue movement or lip pouting. In less cooperative or more severely paretic patients, finger tapping was simplified to simple opening and closing of the hand. For 1 patient unable to perform a motor task, activation was obtained by stroking his hand with a rigid brush (only sensory stimulation). Patients were asked to keep the rest of their body immobilised, in order to avoid head motion. In all cases patient cooperation was visually monitored by a video camera. Our experiments were conducted bilaterally to compare activation sites for their magnitude and position within the brain. All tasks were executed on a self-paced rhythm and the speed varied according to the neurological status of the patient.

For lesions in the insular and lower parts of the parietal lobe, auditory and phonological paradigms were used. These consisted of listening to a tape of clearly pronounced nouns alternated with periods of background noise. In the "word generation" paradigm, patients were asked to associate verbs to nouns (e.g. bird . .. to fly, steak . .. to eat).

MRI acquisition

Images were acquired on a 1.5-T Magnetom Vision MR imager (Siemens, Erlangen, Germany) with fast gradient switching capabilities (25 mT/m in 300 μs). The high-resolution anatomical images were acquired with a 3D MPRAGE sequence (TR/TE/α: 4 ms/10.3 ms/15°; FOV: 256×256 mm^2, 160 partitions; matrix: $256 \times 256 \times 128$ or voxel size $1 \times 1 \times 1.25$ mm^3). For functional imaging, a gradient-echo echoplanar (GE-EPI) technique was used (TR/effective TE/α: 4000 ms/40 ms/90°; FOV: 200×200 mm^2; matrix: 64×64; slice thickness 5 mm; in-plane resolution: 3.13×3.13 mm^2). This sequence allowed acquisition of 32 transversal slices, covering the entire brain. An fMRI time series lasted 8 min and comprised 125 measurements of 32 slices, each spaced 4 s in time. During this time six "task-rest" cycles were performed, each consisting of 20 acquisitions (Fig. 1). Prior to the start of the EPI measurements, a global magnet shim was executed in order to compensate for local field inhomogeneities which induce artefacts and distort the functional images. After shimming, EPI images were rapidly checked in cine mode for head movement or gross variations in signal intensity. Total examination time always remained less than 1 h.

Data analysis

Preprocessing

The raw data were transferred to an off-line workstation for further processing using the SPM96 software package (Wellcome Department of Cognitive Neurology, Hammersmith, London) [8, 9]. The first step is a spatial realignment to correct the images for residual head motion (Fig. 2). The procedure adopted in this step is to estimate head movements using a least-squares algorithm. The contribution of motion in the images can be very prominent due to the long duration of fMRI time series [10].

Images are then normalised into the standard Talairach and Tournoux [25] anatomical space to compare the results with those obtained by other research groups, either with MRI or PET. This spatial normalisation is based on the high-resolution 3D images acquired at the beginning of the experiment. Our normalisation procedure only applies "rigid body" transformation.

The images are subsequently spatially smoothed to enhance the signal-to-noise ratio by convoluting the data with a Gaussian kernel. This kernel was approximately two to three times the in-plane voxel size.

Statistical analysis

The time variance of the MR signal is tested pixelwise in the images for correlation of the task with the haemodynamic response curve, by convoluting the task paradigm with an estimate of the haemodynamic response func-

Table 1. Overview of patient information, diagnosis, activation sites, their relation to lesions and therapy. SF sulcal effacement; DP displacement; DTL distance to lesion; PT predicted therapy; LGA low-grade astrocytoma; AA anaplastic astrocytoma; GM glioblastoma multiforme; AVM arteriovenous malformation; M1 primary motor cortex; S1 primary sensory cortex; SMA supplementary motor area; PMC lateral premotor cortex; AREA Brodman's area; A adjacent (< 15 mm); D distant (> 15 mm)

Patient no.	Age (years)	Gender	Symptoms	Type of lesion	Localisation of lesion	Localisation of activation	DTL	SF	DP	PT	Therapy
1	71	M	Dysaesthesia, left arm	LGA	Right parietal lobe	M1	D			*	Surgery
2	42	F	None	LGA	Right cingulate gyrus	M1,PMC	D			*	None
3	34	M	None	AVM	Right frontal lobe	FAILED					
4	46	M	Paresis, left arm	LGA	Right precentral gyrus	M1,S1	A	+	+	**	Radio-therapy
5	39	F	Paresis, left foot	LGA	Right precentral gyrus	M1,PMC, SMA	A			***	Surgery
6	29	M	Unstable gait	LGA	Right parietal lobe	M1,	D	+	+	*	Surgery
7	62	F	Hemiparesis, left	Haemor-rhage	Left frontal lobe	FAILED					
8	26	F	None	AVM	Right frontal lobe	M1	D			*	Endo-vascular
9	28	F	None	Angioma	Right cingulate gyrus	M1,PMC, SMA	D			****	Endo-vascular
10	24	F	Paresis, right arm	AA	Left pre/post-central gyrus.	M1,S1	A	+	+	**	Radio-therapy
11	26	F	Paresis, right leg	LGA	Right parietal lobe	M1,	D		+	****	None
12	17	F	None	AVM	Right frontal lobe	M1,PMC, SMA	D			*	Endo-vascular
13	65	F	Hemiparesis, left	LGA	Right precentral gyrus	M1,SMA	A			*	Surgery
14	31	M	Partial amnaesia	Haemor-rhage	Right supramar-ginal gyrus	AREA 40, 41,22	D			****	Medical
15	36	M	Seizures, left arm/leg	Pachygyria	Right frontal lobe	M1,PMC	A			****	Medical
16	45	M	Paresis, left arm	LGA	Right precentral gyrus	M1,PMC, SMA	A			**	Radio-therapy
17	64	F	None	AA	Right frontal lobe	M1,SMA,S1	A	+	+	**	Surgery
18	59	M	None	Arachnoid cyst	Left subtotal haemisphere	M1, AREA 40, 41	A	+	+ +	****	None
19	11	F	Unstable gait	Menin-gioma	Left frontal lobe	M1, S1	D			****	Surgery
20	28	F	None	AA	Left insular cortex	AREA 40, 41, 22	A	+	+	**	Radio-therapy
21	45	F	Paresis, left arm	LGA	Right frontal lobe	M1, PMC, SMA	A			*	Surgery
22	50	M	None	LGA	Right cingulate gyrus	M1, PMC, SMA	A			****	None
23	18	M	Seizures in face	AVM	Left precentral gyrus	Excluded					
24	42	M	Paresis, left arm	LGA	Right frontal lobe	M1, PMC, S1	D			***	Radio-therapy
25	57	M	Paresis, left arm	Metastasis	Right parietal lobe	M1, PMC, SMA	D			***	Surgery
26	61	M	None	Metastasis	Left cingulate gyrus	M1, SMA, AREA 40, 41	D			****	Surgery
27	40	F	None	AA	Left frontal lobe	M1, PMC	D			*	Surgery
28	65	M	Paresis, right arm/leg	AA	Left precentral gyrus	M1, SMA	A	+	+	**	Surgery
29	31	M	None	GM	Right parietal lobe	S1	A	+	+	**	Radio-therapy

Table 1. Continued

Patient no.	Age (years)	Gender	Symptoms	Type of lesion	Localisation of lesion	Localisation of activation	DTL	SF	DP	PT	Therapy
30	52	M	Paresis, right arm	LGA	Left frontal lobe	M1, PMC	D			*	Surgery
31	40	M	Hemiparesis, left	GM	Left frontal lobe	M1, PMC, SMA	A	+	+	**	Radio-therapy
32	34	M	None	AA	Left precentral gyrus	M1, PMC	A		+	***	Radiother-apy
33	32	M	Headaches	Angioma	Left precentral gyrus	M1, PMC, SMA	A			**	Endovas-cular
34	47	M	None	LGA	Right frontal lobe	M1, SMA	D			***	Surgery
35	40	M	Paresis, left arm	LGA	Right frontal lobe	M1, PMC, SMA	D			****	None
36	55	M	None	LGA	Left precentral gyrus	M1, PMC	D			*	Radiother-apy
37	68	F	None	AA	Right parietal lobe	M1, SMA	D	+	+	***	Surgery
38	57	M	Paresis, right arm	LGA	Left parietal lobe	M1, S1	D			*	None
39	34	F	None	LGA	Right cingulate gyrus	M1, PMC, SMA	D			*	None
40	17	F	Seizures, right arm	Angioma	Left parietal lobe	M1, PMC, SMA	A			*	Endovas-cular

*Complete agreement with therapy; **not suitable for complete resection; ***better planning of stereotactic procedure; ****no influence or no invasive therapy

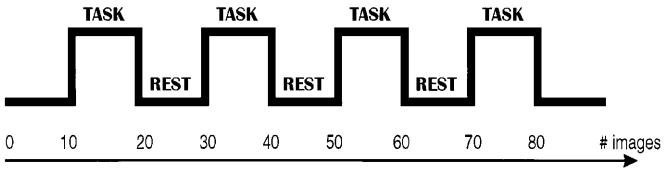

Fig. 1. Example of stimulus paradigm. Task periods alternate with rest periods. Ten sets of images, covering the entire brain, are acquired during each period. One period lasts approximately 45 s. One fMRI time series comprises six cycles or 120 sets of images

tion. This ANCOVA analysis (analysis of covariance) is computed as a statistical parametric map of the t-statistic (SPM(t)). This SPM(t) map is transformed to the unit normal distribution (SPM(Z)) and thresholded at 3.09 ($p < 0.001$ uncorrected) and $p < 0.05$ for extent of activation. The result of this analysis is a map of significantly activated voxels for the relevant computed contrast (activation minus rest). This brain activation map is then overlayed in colour onto the anatomical images. Image processing time takes several hours on an SGI Indigo2 workstation.

Results

The results are summarised in Table 1. Functional MRI was successful in 37 of 39 patients. Adequate imaging failed in 2 patients due to a susceptibility artifact and flow phenomena, respectively. All other patients showed robust differential activation located within the cerebral cortex (e. g. Fig. 3).

Sensorimotor experiments

Activation in the primary motor area (M1) was located in the precentral gyrus and the adjacent central sulcus and was found in all cases. The lateral and medial premotor areas, also referred to as the supplementary motor area (SMA) and lateral premotor cortex (PMC) [11, 13, 15], were found in 55 % of patients (Fig. 2 b). In 20 % of the motor experiments, sensory activation in the postcentral gyrus (S1) was observed.

Auditory and language experiments

Activation was visualised in all 4 patients and was located in the superior temporal gyrus (primary auditory cortex–gyri temporales transversi) and the adjacent angular gyrus. In 2 patients the word generation paradigm revealed activation in the left inferior frontal lobe known as Broca's area 22 (Fig. 4).

Relation of lesions to activation

In 17 cases (see Table 1 for details) the activated regions were immediately adjacent to the lesion (Fig. 5), whereas in the 20 other cases a distance of at least 15 mm could be visualised between the lesion and the fMRI activation sites. No activation was seen in cortex diffusely infiltrated by tumoral tissue or within spared cortex in the nidus of AVMs. Mass effect was present in 12 cases, and in 10 patients there was effacement of the local sulcal anatomy (see Table 1 for details). Figure 6 illustrates a pronounced case of sulcal effacement, due to white matter cytotoxic oedema, secondary to a tumoral lesion. Anatomical landmarks are clearly distorted, reducing

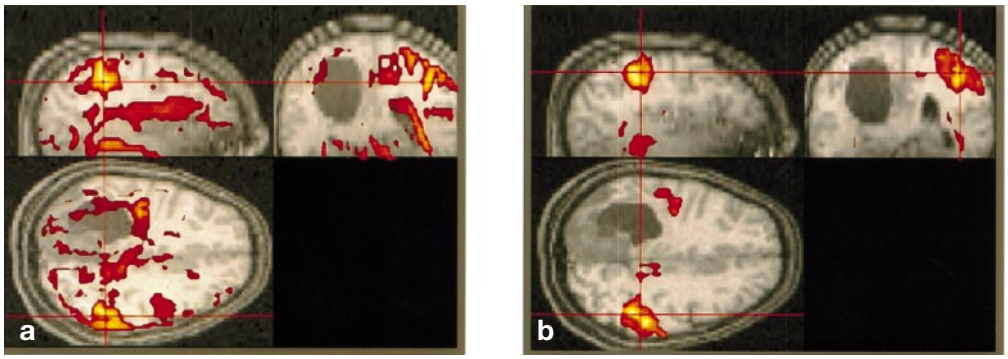

Fig. 2 a, b. Effect of motion correction. Bilateral finger-tapping experiment, analysed **a** without and **b** with motion correction (axial, coronal and sagittal slices). The effect of motion is obvious **(a)**. Bilateral M1 activation is shown in **b**

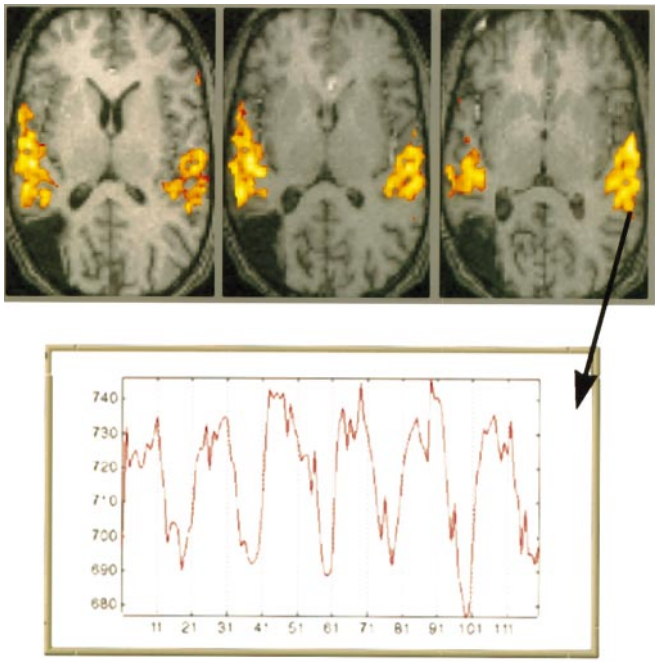

Fig. 3. Plot of signal intensity variations within auditory activation focus (six task-rest cycles). Paradigm used was the "word-listening paradigm"

the accuracy of localisation of the lesion based purely on morphological images.

Impact on therapy

Based on this data, and taking into account the information gathered from clinical examination and other biological and radiological investigations, the best treatment for each patient individually was discussed in consensus between neurosurgeons and radiologists. The predictive value of the fMRI investigations was later assessed following therapy. In 6 cases information from the fMRI investigation actually led to an alteration in the approach of the stereotactic procedure. In 9 cases diagnosis of inoperability was confirmed, and in 11 patients the fMRI had absolutely no influence on the therapy. Of these 11 patients, 1 was lost to follow-up and 1 was not treated at all (due to a congenital disorder, for which no surgical treatment could be offered; see Fig. 5).

Of the 20 cases with lesion-to-activation distance > 15 mm, 8 underwent total resection. One case underwent a subtotal resection because of ingrowth of the tumour within deeper thalamic structures and the posterior horn of the lateral ventricle. Two patients of this group were treated by radiotherapy, because of the histological nature of the lesion. Three patients were treated with intravascular embolisation, and their postprocedural status was uneventful. Seven patients did not require therapy or were treated medically.

Of the 17 lesions with lesion-to-activation distance < 15 mm, as illustrated in Fig. 7, and deemed unsuitable for total resection, 8 received radiotherapeutic treatment. Five patients underwent a subtotal resection. Two lesions were embolised, with postprocedural status unchanged. In 2 patients invasive therapy was not warranted.

Of the 21 patients who underwent either a resection or a biopsy, 3 had a transient neurological deficit contralateral to the side of the lesion. Two of these 3 patients belonged to the group with lesions adjacent to the active areas. All deficits resolved within 7 days post surgery.

In 3 cases the activation visualised was smaller than in other patients; these were all patients which manifested more severe paretic symptoms at the time of the investigation. One patient could not sufficiently perform a motor task, but activation in the postcentral gyrus was obtained by a sensory task, as described previously. The lesions of these last 4 patients were all adjacent to the activation sites.

Comparison with an invasive procedure

Two additional patients with secondary trigeminal neuralgia, not part of the previously mentioned group with lesions, were also studied with motor paradigms of the face and hands (lip pouting and finger tapping). We obtained activation sites in the precentral gyrus at a level below the region of the hand bilaterally, corresponding to the motor area of the facial muscles. The fMRI activation data were matched to high-resolution MRI, acquired in the stereotactic frame of the patient. Coordinates for approach to the motor cortex were determined both with and without the fMRI information by two independent and experienced physicians (S. S. and B. N.)

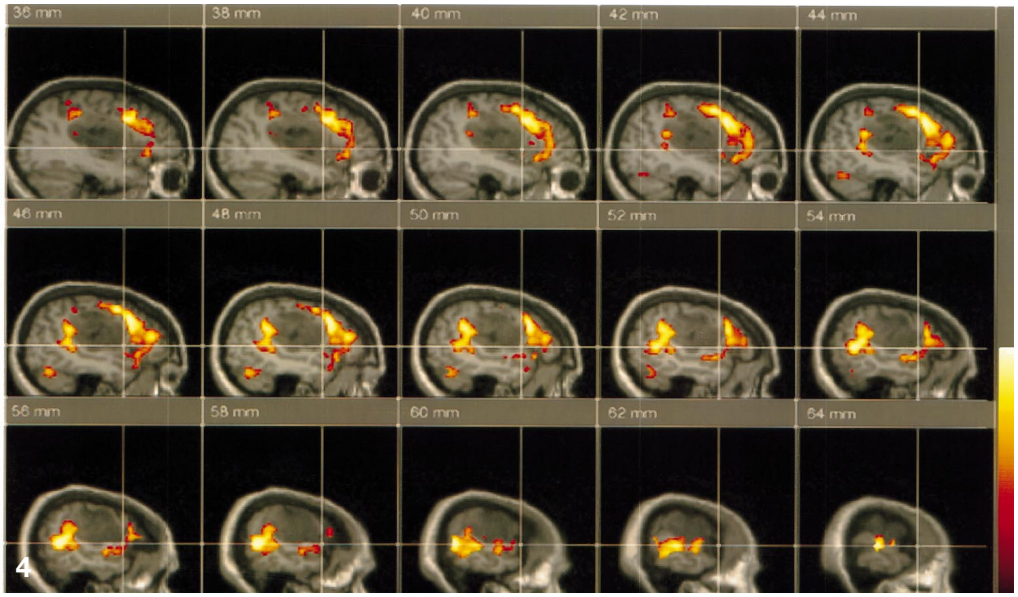

Fig. 4. Activation in superior temporal and left inferior frontal cortex as obtained by the "word-generation" paradigm

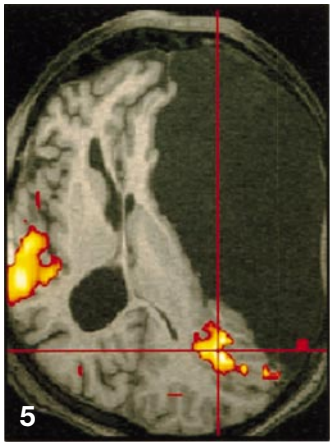

Fig. 5. Bilateral activation of the primary auditory cortex in the presence of an arachnoid cyst in the left hemisphere

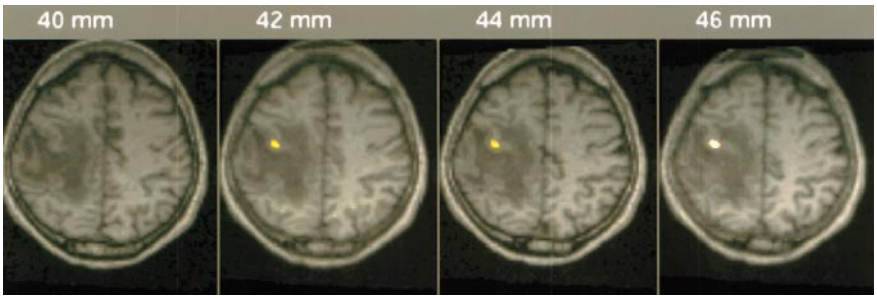

Fig. 6. Activation of primary motor cortex (M1) in a patient with pronounced sulcal effacement. A unilateral finger-tapping paradigm was used

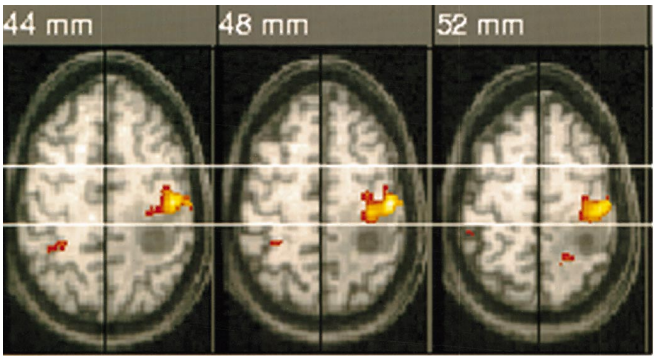

Fig. 7. Example of a lesion with a distance to the activation of the right hand < 15 mm. Unilateral finger-tapping paradigm

and were found to match with a high degree of accuracy. Stimulation electrodes were extradurally implanted at aforementioned coordinates. Postoperatively, both stimulators functioned appropriately, causing face twitching at high stimulation rates and pain relief at lower frequencies, suggesting accurate location from fMRI results.

Discussion

This report describes the result of fMRI in a group of 40 patients with focal cerebral lesions. Some patients presented with mass effect exerted by the lesion involving the sensorimotor cortex, and others showed marked anatomical distortion by or near the mass. In all patients robust activation secondary to task-related behaviour was visualised. In 2 cases the investigation failed because of artefacts inherent to the image acquisition. On three occasions the activation was of poor quality caused by the patients' relative inability to perform the tasks. Whether the degree of impairment in these patients was directly connected to the closeness of the lesions remains unclear. However, in the 1 patient where motor activation could not be obtained, activation related to the sensory task was visualised, confirming that poor motor task execution, rather than proximity of the lesion or oedema, was responsible for the lack of activation. The fMRI technique used a commercial 1.5-T scanner and advanced EPI switching capabilities that can be implemented with a hardware upgrade. Using the same clinical imager and setup, results in young healthy volunteers showed very reproducible brain activation results

in response to visual and sensorimotor function tasks [4, 11, 12]. These data were consistent with results in positron emission tomography (PET) and magnetoencephalography (MEG) [14–17] and two studies using intraoperative electrical motor cortex stimulation [23, 25]. Whereas studies in young volunteers are easily manageable, fMRI in patients with brain lesions remains difficult. Indeed, the success of fMRI brain mapping relies heavily on cooperation both in task execution and in minimizing head motion. Furthermore, the diversity in nature and extent of the lesions described calls for an individual approach towards each patient. Imaging protocols and selection of stimulus paradigm have to be adapted to acquire the most useful spatial information of the peritumoral region. It is therefore obvious that the clinical use of fMRI remains limited to selected patient groups. On the other hand, brain lesions which are limited in extent are very often more amenable to surgery, which implies that the patient group which is eligible for surgery often corresponds to the ideal population for which fMRI is indicated.

Very often, motor stimulation paradigms elicited sensory stimulation, and vice versa. This overlap in activation leads us to believe that the pre- and postcentral gyrus cannot be arbitarily divided into motor- and sensory areas. Recent advances in neuroscience support the theory that there are indeed overlapping functions within these two gyri [18].

Our study suggests that fMRI in patients with focal brain lesions, varying both in nature and extent, can be routinely performed with a high success rate and can contribute to preoperative planning. Activation maps can be obtained even when tumoral tissue is close to eloquent brain tissue. Additional information is gained about local anatomical landmarks, even when these appear distorted on conventional MR images.

In previous studies, accuracy and specificity of fMRI has been compared with PET and MEG data [19–20]. In this study we attempted to verify the accuracy of fMRI brain mapping more directly by comparing the results with postoperative electrocortical stimulation (POECS). Although results seem to correlate well, one has to remain cautious when directly comparing both techniques. Functional MRI registers variations in signal intensity, caused by cerebral changes between task-related behaviour and rest. The operative technique, on the other hand, is based entirely on responses elicited from direct stimulation of the cortex. The fMRI signal is derived from flow in small capillaries draining brain tissue, whereas POECS is based on changes by polarisation of neurons [25].

Nevertheless, the good anatomical and functional correlation between the two different techniques inspires full confidence in the capabilities of fMRI to localise eloquent cortex with high accuracy. Since in this report the comparison was made in only 2 patients, larger series will have to be performed to adequately determine the exact spatial accuracy of fMRI.

Conclusion

Functional MRI in patients with focal brain lesions can be accurately performed in a selected group of patients. Adaptation of the imaging protocol on an individual basis offers robust visualisation of eloquent cortical areas next to lesions of different localisations. Therefore, a dedicated approach is recommended to achieve a high percentage of success in imaging brain function near focal brain lesions. The technique furthermore provides significant clinical information that can contribute to a decrease in postsurgical morbidity. The accuracy of fMRI in patients has been evaluated and compared with different imaging techniques, including invasive monitoring, and a good agreement seems to exist across modalities. Comparison on larger patient groups is still required to further confirm the exact spatial accuracy of fMRI in a clinical context.

References

1. Kwong KK, Belliveau JW, Chessler DA et al. (1992) Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation. Proc Natl Acad Sci USA 89: 5675–5679
2. Bandettini PA, Wong EC, Hinks R et al. (1992) Time course EPI of human brain function during task activation. Magn Reson Med 25: 390–397
3. Turner R, Jezzard P, Wen H, Kwong KK et al. (1993) Functional mapping of the human visual cortex at 4 and 1.5 Tesla using deoxygenation contrast EPI. Magn Reson Med 29: 227–297
4. Connely A, Jackson GD, Frackowiak RSJ et al. (1993) Functional mapping of the activated human primary cortex using a clinical magnetic resonance imaging system. Radiology 188: 128–130
5. Ogawa S, Lee T, Kay A, Tank DW (1990) Brain magnetic resonance imaging with contrast dependent on blood oxygenation. Proc Natl Acad Sci USA 87: 9868–9872
6. Ogawa S, Melon S, Tank DW et al. (1993) Functional brain mapping by blood oxygenation level-dependent contrast magnetic resonance imaging. Biophys J 64: 803–812
7. Bandettini PA, Wong EC, Yoe EA de et al. (1993) Functional dynamics of blood oxygenation level dependent contrast in the motor cortex. Proc SMRM 3: 1382
8. Friston KJ, Jezzard P, Turner R (1994) The analysis of functional MRI time series. Hum Brain Mapping 1: 153–171
9. Friston KJ, Holmes AP, Poline JB et al. (1995) Analysis of functional MRI time-series revisited. Neuroimage 2: 45–53
10. Grootoonck S, Hutton C, Ashburner J et al. (1996) Assessment of movement-related signal changes in fMRI. Hum Brain Mapping 3: S 454
11. Van Oostende S, Sunaert S, Van Hecke P et al. (1997) fMRI studies of the supplementary motor area and the premotor cortex. NeuroImage 6: 181–190
12. Van Oostende S, Sunaert S, Van Hecke P, Marchal G, Orban GA. (1997) The kinetic occipital area in man: an fMRI study. Cereb Cortex 7: 690–701
13. Donogue JP, Sanes JN (1994) Motor areas of the cerebral cortex. J Clin Neurophysiol 11: 382–396
14. Larsson J, Gulyas B, Roland PE (1996) Cortical representation of self-paced finger movement. Neuroreport 7: 463–468
15. Kawashima R, Itoh H, Ono S et al. (1996) Changes in regional cerebral blood flow during self-paced arm and finger movements. Brain Res 716: 141–148
16. Korvenoja A, Wikstrom H, Huttunen J et al. (1995) Activation of ipsilateral primary sensorimotor cortex by median nerve stimulation. Neuroreport 6: 2589–2593

17. Conway BA, Halliday DM, Farmer SF et al. (1995) Synchronisation between motor cortex and spinal motoneuronal pool during the performance of a maintained motor task in man. J Physiol Lond 489: 917–924
18. Geyer S, Ledberg A, Schorman T et al. (1996) Microstructure and function of the primary somatosensory cortex of man: an integrative study using cytoarchitectonic mapping and PET. Hum Brain Mapping 3: S18
19. Ramsey NF, Kirkby BS, Van Gelderen P (1996) Functional mapping of human sensorimotor cortex with 3D BOLD fMRI correlates well with $H_2{}^{15}O$ PET rCBF. J Cereb Blood Flow Metab 16: 755–764
20. Baumann SB, Noll DC, Kondziolka DS et al. (1995) Comparison of functional magnetic resonance imaging with positron emission tomography and magnetoencephalography to identify the motor cortex in a patient with an arteriovenous malformation. J Image Guid Surg 1: 191–197
21. Atlas WA, Howard RS II, Maldjian J et al. (1996) Functional magnetic resonance imaging of regional brain activity in patients with intracerebral gliomas: findings and implications for clinical management. Neurosurgery 38: 329–337
22. Pujol J, Conesa G, Deus J, Vendrell P et al. (1996) Presurgical identification of primary sensorimotor cortex by functional magnetic resonance imaging. J Neurosurg 84: 7–13
23. Yousry TA, Schmid UD, Jassy AG et al. (1995) Topography of the cortical hand area: prospective study with functional MR imaging and invasive cortical mapping at surgery. Radiology 195: 23–29
24. Detre JA, Sirven JI, Alsop DC et al. (1995) Localisation of subclinical ictal activity by functional magnetic resonance imaging: correlation with invasive monitoring. Ann Neurol 38: 618–624
25. Mueller WM, Yetkin F, Hammeke TA et al. (1996) Functional magnetic resonance imaging mapping of the motor cortex in patients with cerebral tumors. Neurosurgery 39: 515–521

Book review

European Radiology

Merrick M. V.: Essentials of Nuclear Medicine, 2nd edn. Berlin, Heidelberg, New York, Springer, 1998, 334 pages, 198 illustrations, 13 in colour, ISBN 3-540-76205-1, DM 148.00

This is an entirely revised and fully updated edition of a textbook published in 1984. Chapters are arranged to correspond to the various organs and address nuclear medicine investigations of skeleton, lungs, urinary tract, heart, endocrine glands, gastro-intestinal tract, blood, infection and inflammation, brain, liver and gallbladder, tumours and soft tissues. There is also a chapter on paediatric applications of radioactive tracer techniques. Finally, the book ends with a concise overview of selected aspects of radiation physics, radiation detectors, including quality control, computers and data processing, radiopharmaceuticals and radiation safety. Appendices indicate the properties of frequently used radio-isotopes and give the most important equations and definitions. An extensive subject index helps the reader to find information quickly.

The various chapters are generally organised according to subchapters which concern radiopharmaceuticals, technical aspects, including procedure protocols, and finally clinical applications. The latter are treated in the clinical context and are compared with other methods of investigation. The case reports are well chosen, but unfortunately, the quality of reproduction of the scintigraphic images is poor and does not live up to the usual standard. Even though the book was not conceived as an atlas, the lack of quality of the pictures is matter for criticism. At the end of many subchapters, one can find references for further reading, which are sometimes helpful, but sometimes disappointing because the reference may concern just a minor subject treated rather than a more in-depth overview of a given question. In some cases, especially in the chapter on bone scintigraphy, the references are out of date. I do not think that the conclusions of clinical studies on the scintigraphic aspects of bone lesions made in the early 1980s are still valid in all circumstances. The resolution of gamma cameras has greatly increased since then and, together with the availability of routinely performed bone SPECT, this allows for much more accurate interpretation of scans, particularly bone scans, in adults as well as in children.

It is rather unusual today to find a textbook which is the work of a single author who passes on to younger generations his long-lasting and outstanding experience. The single authorship makes it very homogeneous and pleasant to read. The clinical and epidemiological background of the various applications is well presented, and the vast experience of the author gives a particularly didactic touch. This book is an excellent introduction to nuclear medicine; it includes the most recent techniques and indications, as well as imaging and non-imaging methods which were frequently used in the past and tend to be forgotten, even though they may still be of use in given situations. It is clear that experienced nuclear medicine physicians might not agree with all the statements made in the monograph, but it would certainly be a great pleasure to argue with the author about some of them. It must also be taken into consideration that several statements on indications and methods reflect medical and economic particularities of the author's professional environment and thus cannot be immediately transferred to other countries.

In summary, despite some imperfections and minor inconsistencies, this is a very useful book for students and trainees in nuclear medicine; it shows the value of radioactive tracer techniques for the diagnosis and treatment of a wide range of diseases. It is very easy to read, fully packed with information, and never boring. It is also helpful for the practitioner in nuclear medicine who will find a lot of information on less frequently performed diagnostic tests or rare pathologies. Its pleasant style makes it accessible to non-nuclear medicine specialists and to technical and nursing staff. Furthermore, it contains a digest of knowledge that makes it a precious tool for preparing teaching material. Last but not least, the concise but rather extensive information in this book is offered at an affordable price.

A. Bischof Delaloye, Lausanne