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Functional magnetic resonance imaging of motor and language for preoperative planning of neurosurgical procedures adjacent to functional areas

Mehran Mahvash [a,*], Homajoun Maslehaty [d], Olav Jansen [c], Hubertus Maximilian Mehdorn [b], Athanasios K. Petridis [d]

[a] Department of Neurosurgery, Clinic of Köln-Merheim, University of Witten-Herdecke, Cologne, Germany
[b] Department of Neurosurgery, University Hospitals of Schleswig-Holstein, Campus Kiel, Germany
[c] Institute of Neuroradiology, University Hospitals of Schleswig-Holstein, Campus Kiel, Germany
[d] Department of Neurosurgery, Klinikum Duisburg, Sana Kliniken, Academic Teaching Hospital of University Essen-Duisburg, Germany

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ABSTRACT

Objective: Functional magnetic resonance imaging (fMRI) for motor and language mapping is used for presurgical planning. This study aimed to evaluate the value of fMRI in clinical routine for preoperative planning of brain surgery adjacent to functional brain areas.
Methods: Thirty-seven consecutive patients with brain lesions adjacent to sensomotor and/or language functional areas underwent fMRI prior to planned brain surgery on a 3 T MRI scanner for identification of motor in all and language functional areas in 29 patients. Analysis software installed on the MRI console was used for rapid image analysis and direct visualization. All fMRI results were analyzed according to the use for preoperative planning.
Results: fMRI data analysis and visualization was possible in less than 10 min. In 35 patients fMRI of motor cortex and in 25 patients fMRI of language could be performed due to the patient's compliance. In 34 patients motor activity could be clearly identified in the precentral gyrus. The dominant hemisphere could be identified clearly in 22 cases. In 18 patients direct anatomical correlation of the activity maps to the speech area of Broca and/or Wernicke could be made. Resection surgery was performed in all patients. 11 patients underwent awake surgery with intraoperative cortical stimulation.
Conclusion: fMRI for clinical routine is a reliable and rapid method for identification of functional brain areas prior to brain surgery adjacent to functional areas. This method allows direct monitoring of the data quality and visualization without being time consuming. Knowledge about the relation of functional areas to the brain lesions improves the preoperative planning, the operation strategy and decision making with patients.

1. Introduction

Precise anatomical localization of brain lesions and their relation to functional areas is one of the most important issues in the preoperative planning of microsurgical procedures to achieve maximal resection and to minimize the risk of neurological impairments.

Several studies have shown that complete resection of malignant tumors like glioblastomas is associated with a prolonged survival rate in adults and children [1–3]. Complete resection is also an independent predictor for good outcome and recurrence free interval for benign brain tumors [4,5]. Even in epilepsy surgery the complete resection of epileptogenic lesion or zone using visualization technologies improves the postoperative outcome of seizure control [6,7]. However, complete resection of a lesion is only indicated if functional areas of the brain can be preserved. There are invasive and non invasive methods to identify the functional areas like cortical electrophysiological mapping, cortical stimulation, transcranial magnet stimulation and functional MRI (fMRI) [8–17].

Functional MRI is based on the blood–oxygen-level dependent (BOLD), a hemodynamic and metabolic basis showing significant changes by neuronal activity. fMRI for preoperative planning and intraoperative guidance of brain surgery has been discussed

* Corresponding author. Tel.: +49 221 8907 3780; fax: +49 221 8907 3997.
E-mail address: mmahvash@yahoo.de (M. Mahvash).

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controversially. Several studies compared fMRI with cortical stimulation, indicate fMRI to be a reliable technique [11,18]. Other studies reported limitations, particularly for language mapping [12,19,20]. Although there is still no class I study of evidence for the value of preoperative or intraoperative fMRI for neurosurgical procedures, in many neurosurgical centers fMRI is performed before brain tumor surgery adjacent to functional areas. Therefore, a critical view and evaluation is necessary to find out if fMRI provides additional information preoperatively to influence the operative strategy and guide brain tumor surgery intraoperatively.

The aim of this study was to evaluate the value of functional magnetic resonance imaging (fMRI) for motor and language mapping for presurgical planning of surgery adjacent to functional brain areas in the clinical routine.

2. Material and methods

In the present study 37 consecutive patients (19 male, 18 female, mean age 48, range 16–78 years) with brain lesions (intra- and extraaxial) were included (Table 1). All patients had preoperative structural MRI showing brain lesions located adjacent to the sensomotor and/or language functional cortex. In all 37 patients functional MRI of motor cortex and in 29 patients fMRI of language was performed prior to brain surgery on a 3 T MRI scanner (Philips, Achieva 3.0 T, Netherlands). Functional MRI scans were performed in block design tasks with the standard method of blood–oxygen-level dependent (BOLD) (echoplanar imaging sequence, 3.0 T, Philips, Achieva, EPI-T2*, TR = 3000 ms, TE = 45 ms, 80 × 80 matrix, FOV = 256 × 256 mm, flip angle = 90°, slice 3 mm, gap 0.3 mm). fMRI scans with motor mapping tasks included fist closure, flexion/extension of the toes and tongue movement with closed mouth. Language mapping was performed with word and sentence generating tests showing letters or words with a head mounted display integrated on the head coil. Analysis software (Philips tool, IViewBOLD) directly installed on the console was used for image analysis and nearly real time visualization of the activation maps. The results were verified while the patient was still in the scanner. Motion correction and threshold selecting has been performed directly on the MRI console. There was no need of data loading, transfer or post processing. The activation maps of fMRI were co-registered and matched to T1-weighted anatomical MR images. Using anatomical MRI and functional maps, the shortest distance between the lesion and the functional cortex as defined by fMRI was measured [8]. fMRI results were used for the planning of surgical strategy due to the identification of functional areas in relation to the resection margin and to inform the patients about potential limited resection, the risk of surgery and possible postoperative deficits. In patients with a decision for surgical resection, the alternative procedure of brain surgery in local anesthesia (awake) was discussed and offered to all patients. Awake surgery was offered to patients preferentially if the distance of functional cortex to the lesion was <10 mm. Neuropsychological testing was performed in all patients preoperatively. After preoperative evaluation, all patients underwent craniotomy and tumor resection surgery. Image guided surgery (neuronavigation) was used in all patients. Postoperative follow-up was within 3 months, than 6 and 12 months after surgery. Preoperative fMRI of motor and language was evaluated on the following aspects: (1) the value of additional information by fMRI for preoperative planning, and (2) influence of fMRI for the surgical strategy and decision making.

Table 1
Patients details.

Number of patients	37 (100%)
Sex	
Male	19 (51%)
Female	18 (49%)
Mean age year (range)	48 (16–78)
Preoperative deficits	
Hemiparesis	16 (43%)
Incomplete aphasia	12 (32%)
Seizure	14 (38%)
Histology	
Glioblastoma WHO IV	15 (40.5%)
Brain metastasis	6 (16%)
Astrocytoma WHO III	5 (13.5%)
Astrocytoma WHO II	3 (8%)
Cavernomas	3 (8%)
Meningiomas	2 (5%)
Arteriovenous malformation	2 (5%)
Edendymoma	1 (3%)

3. Results

Data analysis and visualization was possible in less than 10 min using the analysis software directly installed on the MR console computer (Fig. 1). Table 2 shows the details of the fMRI and surgery. The localization of the lesions was on the left side in 29 and on the right side in 8 patients. Preoperative neurological deficits were as follows: hemiparesis in 16 and incomplete aphasia in 12 patients. Focal and generalized seizure occurred in 14 patients. Postoperative neurological outcome showed impairment of the preexisting hemiparesis in 3 patients and new hemiparesis in 1 patient. In 5 patients the preexisting paresis improved postoperatively. Impairment of the incomplete aphasia was seen in 3 patients.

The histology of the brain lesions revealed glioblastoma multiforme WHO grade IV in 15, cerebral metastasis in 6, astrocytoma WHO grade III in 5, astrocytoma WHO grade II in 3, cavernomas in 3, meningiomas in 2, arteriovenous malformation in 2 patients and ependymoma in one case.

Postoperative MRI was performed to evaluate the completeness of resection. Complete surgical resection was achieved in 28 patients, incomplete resection was performed in 9 patients. The patients with incomplete resection had glioblastoma in 7 and astrocytoma WHO grade III in two cases.

From 37 patients, in 2 patients fMRI investigation of motor cortex was not possible due to the compliance of the patients. From the 35 patients the motor cortex could be identified clearly in 34 cases. The identification was also possible in patients with hemiparesis. In 28 patients the clear identification of motor cortex on structural MRI was not possible due to the brain tumor and its perifocal edema. In all of these 28 cases fMRI gave additional information to identify the motor cortex which was not otherwise visible. These informations were analyzed and used by the neurosurgeons preoperatively in all cases. From 37 patients 29 underwent fMRI for language mapping. From 29, in 25 patients the investigation was possible due to the compliance. Using fMRI results, the dominant hemisphere could be identified clearly in 22 cases (Fig. 2). In other 3 cases fMRI activity was seen in both hemispheres with a tendency to a hemisphere but was not considered as a reliable identification of the dominant hemisphere. Although all fMRI signal activities did not correspond to the classic pattern of neuroanatomical language regions, fMRI signals in the direct anatomical neighborhood of the Broca and Wernicke region were detected in 18 patients.

fMRI was used to plan the surgical strategy in all cases in which fMRI was successful (motor cortex in 34, language in 25 patients). Using fMRI of motor cortex, in 15 patients the distance of the lesion to functional cortex was measured <10 mm, in 19 patients 10 mm or more. fMRI of language showed a distance <10 mm in 11 and 10 mm or more in 14 cases. Due to fMRI results and anatomical