Meet Am Soc Stereotact Funct Neurosurg, Snowbird, Utah, 1999
Stereotact Funct Neurosurg 1999;72:95–102

Stereotactic and Functional Neurosurgery

# Concordance between Functional Magnetic Resonance Imaging and Intraoperative Language Mapping

M.I. Ruge[a] J. Victor[c] S. Hosain[c] D.D. Correa[a,c] N.R. Relkin[c]
V. Tabar[b] C. Brennan[b] P.H. Gutin[b] J. Hirsch[a,c]

Departments of [a]Neurology and [b]Neurosurgery, Memorial Sloan-Kettering Cancer Center, and [c]Department of Neurology and Neuroscience, Weill Medical College of Cornell University, New York, N.Y., USA

Key Words
Functional magnetic resonance imaging · Language mapping · Intraoperative electrophysiology

Abstract

Although the correspondence between functional-magnetic resonance imaging (fMRI) representations of the sensorimotor cortex and intraoperative electrophysiology (including somatosensory evoked potential, SSEP, recordings and direct cortical stimulation) has been reported, a similar correspondence between fMRI and intraoperative localization of the language-sensitive cortex is not as well established. The aim of the present study was to evaluate the concordance between fMRI and intraoperative electrophysiology with respect to the localization of the language-sensitive and sensorimotor cortices. We present the results of 21 patients who underwent language and sensorimotor mapping by fMRI and intraoperative electrophysiology including SSEP recordings (n = 21), direct cortical stimulation of motor cortex (n = 15) and direct cortical stimulation of Broca's and Wernicke's area (n = 5). When responses were obtained with both methods, localization of function concurred in all cases. These observations suggest that fMRI represents a reliable preoperative tool for the identification of language-sensitive areas.



KARGER

Fax + 41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com


1011–6125/99/0724–0095$17.50/0

Accessible online at:
www.karger.com/journals/sfn

Dr. M.I. Ruge, Memorial Sloan-Kettering Cancer Center
Neurology, fMRI Laboratory, 1275 York Avenue
Box 506, New York, NY 10021 (USA)
Tel. +1 212 639 2276, Fax +1 212 794 5863
E-Mail hirsch@vision.mskcc.org

## Introduction

Functional magnetic resonance imaging (fMRI) provides a noninvasive tool for preoperative localization of sensorimotor and language functions that might be at risk during tumor resections. Identification of primary motor and sensory cortex by fMRI has been confirmed by comparison with intraoperative electrophysiology [1–3]. The concordance between fMRI and Wada testing with respect to the determination of the language-dominant hemisphere has also been demonstrated [4, 5]. However, there is little information available comparing fMRI and direct cortical stimulation of language-sensitive areas in the awake patient. The purpose of this study was to evaluate the results of fMRI and intraoperative electrophysiology and to determine the concordance of both techniques with respect to the language-sensitive areas and sensorimotor cortices.

## Methods

*Patient Population*

Twenty-one neurosurgical candidates with supratentorial neoplasms (9 females, 12 males; average age 44 ± 14 years; age range 11–71 years) were studied. Sixteen patients had lesions located in or close to the primary sensorimotor cortex, and 5 patients had lesions involving the left superior temporal gyrus, the putative Wernicke's area. All patients were found to be right-handed according to the Edinburgh Handedness Inventory [6]. Five patients with lesions in Wernicke's area underwent a neuropsychological evaluation to assess cognitive and particularly language functions prior to surgery.

*Functional Magnetic Resonance Imaging*

All 21 patients underwent the fMRI investigation in conjunction with a regular anatomical head MRI prior to surgery. As part of our fMRI task battery [7] we used a finger-thumb tapping task and tactile stimulation of hand, face or foot to functionally identify pre- and postcentral gyrus. Picture naming and listening to words tasks were employed to activate the putative Broca's and Wernicke's areas. These tasks were performed during a 40-second activation period. Images were collected using a standard echoplanar functional imaging sequence (GE 1.5 T; echo planar, T2*, TR = 4,000, TE = 60, flip angle = 60°; 21 continuous 4.5-mm-thick axial slices aligned parallel to the AC-PC line). Data were processed using a t test-based statistical coincidence analysis to identify areas of functional activation [8, 9].

*Intraoperative Electrophysiology*

All 21 patients underwent intraoperative monitoring and epicortical recordings of somatosensory evoked potentials (SSEPs), and in 15 of these cases direct cortical stimulation was performed [10, 11]. The 5 cases in which language-sensitive areas appeared to be at risk during resection underwent an additional awake language mapping procedure involving direct cortical stimulation of Broca's and Wernicke's area [12–14].

*SSEP Recordings*

After anesthesia and preparation, needle-recording electrodes were placed at Erb's Point, and stimulating electrodes were placed over the left or right median nerve at the wrist. Following craniotomy and exposure of cortex, subdural strip electrodes were systematically placed by the surgeon in the operative field. The median nerve was stimulated to elicit epicortical responses that could be measured with the electrodes. A consistent phase reversal registered between electrode sites allowed the physiological identification of sensorimotor cortex and therefore the central sulcus. These recordings of somatosensory evoked potentials were made with the 8-Channel Viking IV® and standard filter settings (30 Hz to 3 kHz).

*Direct Cortical Stimulation*

Direct cortical stimulation of the exposed cortex was performed using the Ojemann bipolar stimulator (1-second trains of 1-ms pulses at 60 Hz), varied from 2 to 18 mA, peak to peak. Different locations were stimulated in a systematic way, and motor responses of hand, face or foot, as well as instances of language dysfunction were documented.

*Awake Language Mapping Procedure*

After craniotomy and recording of SSEPs, the patient was awakened and was asked to count forward and backward while the cortex in the putative Broca's area was stimulated as described above. Subsequently, the same picture-naming paradigm used in our fMRI standard battery of tasks was administered to confirm the sites resulting in speech disruption in Broca's area. Stimulation was systematically repeated and extended to the temporal lobe cortex, and sites of activation revealed by the fMRI maps were specifically targeted.

*Correlation of Findings*

Locations on the cortex which elicited either a phase reversal during the recording of SSEPs, motor responses or language dysfunction during the direct cortical stimulation were tagged and photographically documented. Using a frameless-based intraoperative navigation system (Elekta Instruments Inc., Atlanta, Ga., USA; BrainLAB GmbH, Munich, Germany), the tagged locations were referenced to anatomical axial MR images localized using a viewing wand, and subsequently compared with areas of activation on corresponding fMRI images [15].

## Results

*Functional Magnetic Resonance Imaging*

The finger-thumb tapping task revealed the precentral gyrus in 20/21 cases (95%), and the tactile stimulation demonstrated activation of the postcentral gyrus in 18/21 cases (85%). Using the combined information of both tasks, the location of the central sulcus could be predicted in all cases.

For the 5 patients undergoing intraoperative language mapping, the results of both picture naming and listening to spoken words tasks revealed activation in Broca's area on the left. The putative Wernicke's area was activated in 3/5 cases in

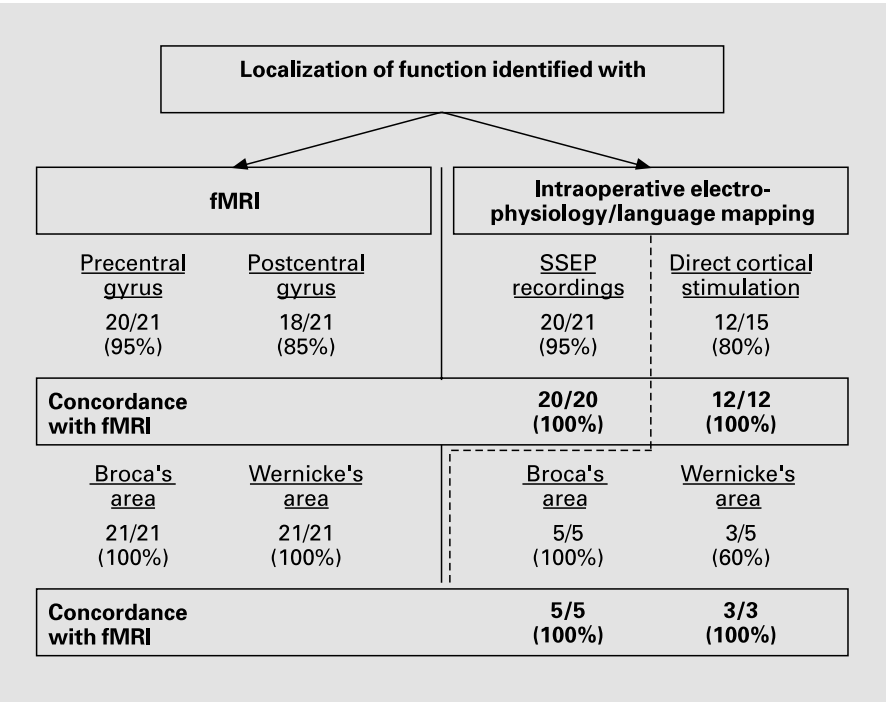



Fig. 1. Comparison of results between fMRI and intraoperative electrophysiology (SSEP recordings and direct cortical stimulation) of the sensorimotor cortex and language-sensitive areas with respect to the localization of these functions. The SSEP recordings elicited phase reversals above the central sulcus and the direct cortical stimulation resulted in either motor responses (postcentral gyrus); speech arrest (Broca's area) or language dysfunction (Wernicke's area). The dotted line separates the areas identified by direct cortical stimulation.

the expected location on the left hemisphere. Interestingly, 2 cases with low-grade gliomas showed the bulk of activation in the contralateral superior temporal gyrus (fig. 1).

*Intraoperative Electrophysiology*

The SSEP recordings showed phase reversals over the central sulcus in 20/21 cases (95%), and direct stimulation of the precentral gyrus provoked motor responses in 12/15 cases (80%). Stimulation of Broca's area resulted in speech arrest in 5/5 (100%) cases (fig. 1). Word-finding difficulties, literal and semantic paraphasic errors were found with stimulation in Wernicke's area of the dominant hemisphere in 3/5 patients. The two remaining patients did not demonstrate

any language dysfunction despite thorough stimulation. In these patients, the fMRI results demonstrated activity in the contralateral superior temporal gyrus, suggesting the possibility of some language representation on this side.

*Correlation of Findings*

Electrophysiological testing identified the sensorimotor cortex in the majority of cases, and these concurred with the fMRI results. Broca's area was identified consistently with both electrophysiology and fMRI and concurred concerning its exact location in all cases.

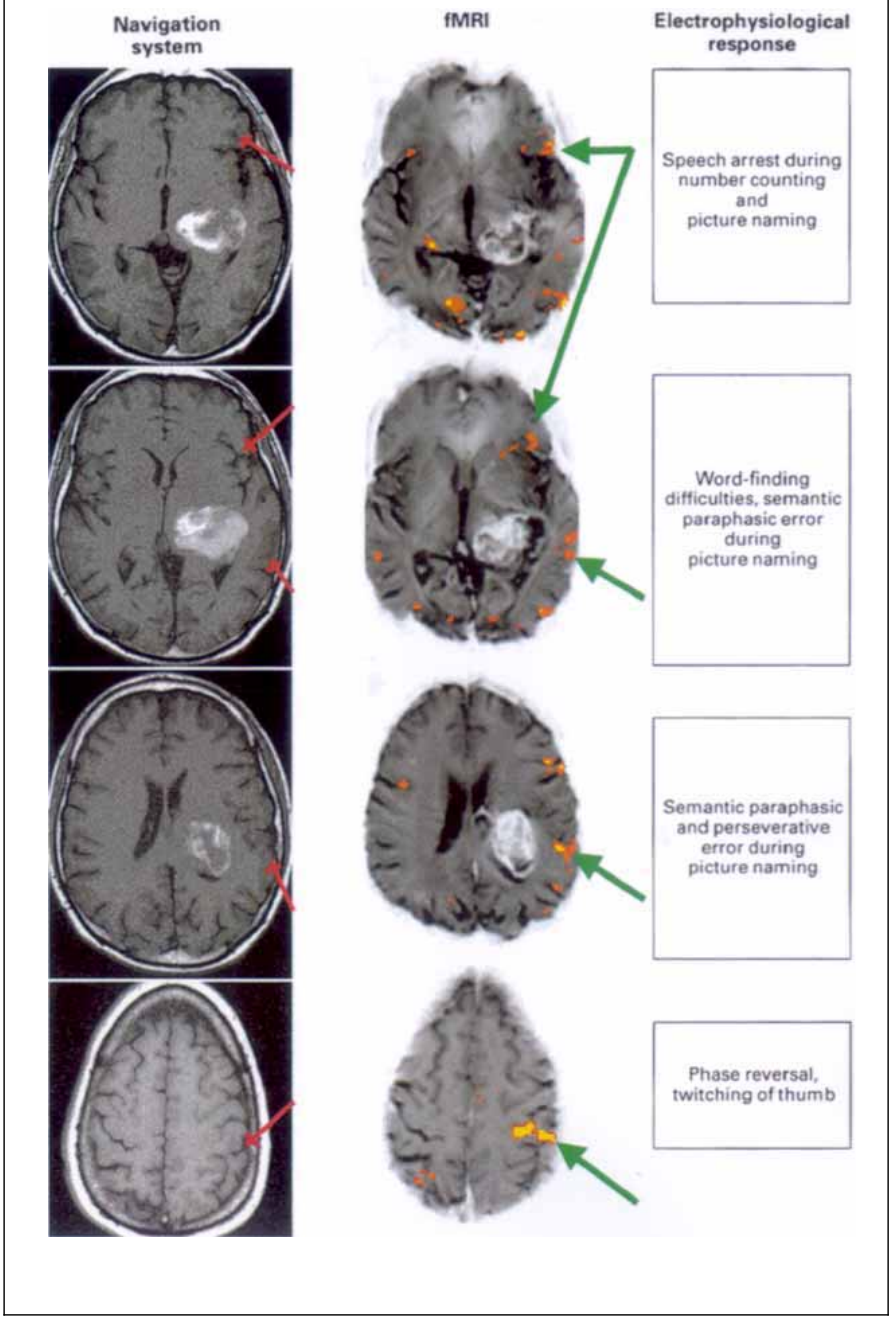
In 3/5 patients, both techniques identified the same area of the left superior temporal gyrus as the putative Wernicke's area (fig. 1).

## Discussion

Considering that fMRI maps are acquired prior to surgery, the procedure contributes to surgical planning, particularly in cases where eloquent cortex might be displaced or affected by lesions. fMRI also reveals information about additional brain regions (i.e. supplementary motor area, contralateral pre- and postcentral sulcus, premotor cortex and basal ganglia), which may not be available for direct simulation during surgery due to various factors such as the extent of craniotomy, anesthesia and equipment-related restrictions (i.e. intraelectrode distance). Additionally, fMRI permits the identification and localization of contralateral language-sensitive areas which may provide compensatory language functioning in patients with slowly progressing lesions affecting language-related areas. However, whether the extent of activation in these areas correlates with postsurgical recovery is at present unknown. In sum, the sequential use of these two methods provides the advantage of improved preoperative planning and direct intraoperative confirmations, and may optimize both surgical procedure and outcome.

## Illustrative Case Report

Patient I.M. is a 35-year-old-right-handed male, who reported occipital headaches, dizziness and hypersomnolence. He also noticed mild word-finding and concentration difficulties, and was found to have mild weakness of the right arm and leg with sensory changes. A MRI scan was performed and demonstrated a cystic, contrast-enhancing mass in the medial portion of the left temporal lobe extending into the parietal lobe and the posterior thalamus with displacement of the midline. Biopsy results were consistent with an anaplastic astrocytoma. Due to the proximity of the tumor to Wernicke's area, an fMRI investigation was performed prior to surgery as described above. Broca's area, Wernicke's area and the pre- and postcentral gyrus were successfully located. During surgery, the recording of SSEPs



demonstrated phase reversals with different intensities in various locations around the central sulcus. These locations were confirmed with direct cortical stimulation at 14 mA, which elicited motor responses in two locations. While stimulating Broca's area, a complete speech arrest during number counting and picture naming was repeatedly observed. Stimulation in Wernicke's area during the picture-naming task resulted in word-finding difficulties, semantic paraphasic and perseverative errors in distinct locations (fig. 2). A subtotal resection was achieved, and the patient developed a transient aphasia immediately after surgery. An informal follow-up examination suggested improvement in his language functions.

## Conclusion

This study demonstrates the accuracy of fMRI in localizing Broca's and Wernicke's areas. A comparison between direct cortical stimulation and fMRI results found good concordance between these methods. Furthermore, the findings confirm previous reports regarding the reliability of fMRI as a technique for the preoperative identification of primary sensorimotor cortex.

## References


1 Puce A, Constable T, Luby ML, Eng M, 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.
2 Yousry TA, Schmid UD, Jassoy AG, Schmidt D, Eisener WE, Reulen HJ, Reiser MF, Lissner J: Topography of the cortical motor hand area: Prospective study with functional MR imaging and direct motor mapping at surgery. Radiology 1995;195:23–29.
3 Schulder M, Maldijian JA, Liu WC, Holodny AI, Kalnin AT, Mun IK, Carmel PW: Functional image-guided surgery of intracranial tumors located in or near the sensorimotor cortex. Neurosurgery 1998;89:412–418.
4 Binder JR, Swanson SJ, Hammeke TA, Morris GL, Mueller WM, Fischer M, Bendalis S, Frost JA, Rao SM, Haughton VM: Determination of language dominance using functional MRI: A comparison with the Wada test. Neurology 1996;46:978–984.
5 Yetkin FZ, Swanson S, Fischer M, Akansel G, Morris G, Mueller W, Haughton V: Functional MR of frontal lobe activation: Comparison with Wada language results. AJNR 1998;19:1095–1098.
6 Oldfield RC: The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia 1971;9:97–113.
7 Hirsch J, Kim K, Lee K-M, Krol G, Souweidane M: A four-part battery of fMRI tasks for neurosurgical planning. Proc Int Soc Magn Reson Imag 1997;1:694.
8 Hirsch J, DeLaPaz R, Relkin NR, Victor J, Kim K, Li T, Borden P, Rubin N, Shapley R: Illusory contours activate specific regions in human visual cortex: Evidence from functional magnetic resonance imaging. Proc Natl Acad Sci USA 1995;92:6469–6473.


Fig. 2. Localization of observed stimulation results (right column) in Broca's, Wernicke's and the central sulcus area using an intraoperative navigation system (left column). Corresponding loci of activity revealed by fMRI tasks (picture naming, listening to spoken words and finger-thumb tapping) are shown in the center column.

9 Kim KHS, Relkin NR, Lee K-M, Hirsch J: Distinct cortical areas associated with native and second languages. Nature 1997;388:171–174.
10 Dinner DS, Luders H, Lesser RP, Morris HH: Cortical generators of somatosensory evoked potentials to median nerve stimulation. Neurology 1987;37:1141–1145.
11 Cedzich C, Taniguchi M, Schafer S, Schramm J: Somatosensory evoked potential phase reversal and direct motor cortex stimulation during surgery in and around the central region. Neurosurgery 1996;38:962–970.
12 Ojemann G, Ojemann J, Lettich E, Berger M: Cortical language localization in left dominant hemisphere: An electrical stimulation mapping investigation in 117 patients. J Neurosurg 1989;71:316–326.
13 Haglund MM, Berger MS, Shamseldin M, Lettich E, Ojemann GA: Cortical localization of temporal lobe language sites in patients with gliomas. Neurosurgery 1995;34:567–576.
14 Herholz K, Reulen HJ, von Stockhausen H, Thiel A, Ilmberger J, Kessler J, Eisner W, Yousry TA, Heiss W: Preoperative activation and intraoperative stimulation of language-related areas in patients with glioma. Neurosurgery 1997;41:1253–1262.
15 Ruge MI, Victor J, Souweidane MM, Bilsky M, Gutin PH, Hirsch J: Identification of pre- and post-central sulcus by functional magnetic resonance imaging and electrophysiology: Comparison in 11 cases. J Cogn Neurosci 1999;(suppl):30.