Location of the sensorimotor cortex: functional and conventional MR compared.

F Z Yetkin, R A Papke, L P Mark, D L Daniels, W M Mueller and V M Haughton

AJNR Am J Neuroradiol 1995, 16 (10) 2109-2113
http://www.ajnr.org/content/16/10/2109

Location of the Sensorimotor Cortex: Functional and Conventional MR Compared

F. Zerrin Yetkin, R. Anne Papke, Leighton P. Mark, David L. Daniels, Wade M. Mueller, and Victor M. Haughton

PURPOSE: To determine the value of functional MR imaging to supplement conventional MR imaging for locating the rolandic cortex. **METHODS:** Parasagittal MR images acquired in conjunction with functional MR images were reviewed. The central sulcus was identified on the MR images by conventional parcellation methods. In the functional MR images, the sensorimotor cortex (rolandic cortex) was identified by the activation secondary to finger and thumb movement or tactile stimulation of the palm. The location of the central sulcus and rolandic cortex was compared. **RESULTS:** In 18 of 23 studies, the central sulcus selected by anatomic criteria coincided exactly or approximately with the cortex activated by the motor or sensory tasks. In two cases of tumor, the rolandic cortex could be located by means of the activation, but the central sulcus was not identified because of severe distortion of anatomic landmarks. In two volunteers, the central sulcus identified by anatomic landmarks did not coincide with the activated cortex. **CONCLUSION:** This study demonstrates that functional imaging supplements anatomic imaging in locating the sensorimotor cortex. Functional MR imaging may be a useful adjunct to conventional MR imaging to determine noninvasively the proximity of eloquent brain to focal brain lesions.

Index terms: Brain, anatomy; Magnetic resonance, comparative studies; Magnetic resonance, functional

AJNR Am J Neuroradiol 16:2109–2113, November 1995

In the selection of patients for craniotomy, the risk of a postoperative neurologic deficit resulting from intraoperative damage to eloquent brain is evaluated. The risk of injury to the rolandic (sensorimotor) cortex is conventionally assessed by using anatomic landmarks visualized in the magnetic resonance (MR) images to determine the distance between the central sulcus and the surgical margins (1). One report suggests that locating the rolandic cortex by anatomic landmarks in MR is unreliable in 16% of healthy subjects and in 35% of patients (2). Alternative methods of identifying the rolandic cortex include magnetoencephalography (2), positron emission tomography (3, 4), and functional MR imaging (5, 6). Early observations suggest that the activation identified noninvasively by functional MR imaging secondary to motor tasks corresponds exactly to the rolandic cortex as identified by intraoperative cortical mapping techniques (5, 6). With functional MR imaging, unlike magnetoencephalography and positron emission tomography, anatomic images are acquired simultaneously with the functional images. The purpose of this study was to determine whether functional MR imaging provides location information that significantly affects the assessment of the proximity of the rolandic cortex to the surgical margins. We selected two series of subjects: one group with cerebral tumors that distort the anatomic landmarks used to locate the central sulcus, and another group (volunteers and patients with epilepsy) with no evidence of a cerebral mass.

Patients and Methods

Patients in whom functional MR imaging was performed before a craniotomy, which exposed portions of the frontal, parietal, or temporal lobe, and volunteers were in-

Received December 2, 1994; accepted after revision June 26, 1995.

From the Departments of Radiology (F.Z.Y., R.A.P., L.P.M., D.L.D., V.M.H.) and Neurosurgery (W.M.M.), The Medical College of Wisconsin, Milwaukee.

Address reprint requests to Victor M. Haughton, MD, Department of Radiology, The Medical College of Wisconsin, John L. Doyne Hospital, 8700 W Wisconsin Ave, Milwaukee, WI 53226.

AJNR 16:2109–2113, Nov 1995 0195-6108/95/1610–2109

cluded. A sagittal plane of a section was chosen for functional MR that provided a close approximation to the photographic record of the surgical exposure of the brain surface in the patients. The location of "activation" in the functional MR was compared with the central sulcus identified in anatomic images in the same planes.

The subjects included 9 patients with partial complex epilepsy and normal cerebral MR images, 3 patients with cerebral tumors, and 10 healthy volunteers. The 12 patients selected for functional MR were candidates for intraoperative stimulation mapping. All subjects had functional MR mapping of tactile sensory and motor function for one hand, which in the surgical candidates was the hand contralateral to the planned craniotomy. The functional and anatomic images were acquired on a commercial 1.5-T imager with a research gradient coil and a radio frequency head resonator insert. A series of locater images was obtained from which anatomic reference images in the sagittal plane were acquired with spin-echo acquisition, 600/20/2 (repetition time/echo time/excitations), 128 × 256 matrix, 20-cm field of view, and 1-cm section thickness. Contiguous planes of a section were acquired from the midline to the lateral surface of the brain at its widest point.

For the functional images, a series of single-shot, blipped, gradient-echo echoplanar images was acquired in each of the anatomic planes (7). The gradient strength is 2 G/cm, and the rise time is 92 microseconds. The series consisted of 140 consecutive images in the selected plane at 1-second intervals with 1000/40, 64 × 64 matrix, 20-cm field of view, 1-cm section thickness, and 40-millisecond acquisition time. The 140-second acquisition included four 20-second periods of rest alternating with three 20-second periods during which the motor or the sensory task was performed. The motor task consisted of the patient's apposing the thumb and first finger repeatedly, rhythmically, and rapidly (2 Hz or greater) (7), and the sensory task consisted of the investigator's scratching the palm of the subject's hand with his or her fingertips (8). The hemisphere contralateral to the hand used was imaged.

Functional images were generated from the 140 consecutive echoplanar images by cross-correlating the signal intensity in each pixel with a reference function. The reference function was a square wave with a period of 40 seconds. In the cross-correlation analysis, the first 5 seconds in each 20-second period were disregarded, and the threshold was set at 0.7, for which the *P* value is calculated at 10^{-5} per pixel. Temporally correlated changes in signal intensity were displayed as "activated pixels" on the anatomic images. The pixels activated by either the motor or the sensory task were used to define the rolandic cortex. In patients who underwent craniotomy, the functional MR map of activation was compared with the photographic recording of intraoperative cortical stimulation mapping.

Two investigators reviewing the anatomic images without knowledge of the functional information selected the central sulcus by consensus. The anterior horizontal and anterior ascending rami of the Sylvian fissure were identified (9). The inferior frontal gyrus was defined as the gyrus framing the anterior rami. The precentral sulcus was selected as the sulcus adjacent to the posterior border of the inferior frontal gyrus. Its superior extension was identified. The central sulcus was selected as the first sulcus posterior to the precentral sulcus.

Relationship of central sulcus to activation

	Patients	Volunteers
Convergent with activation	10	9*
Not convergent with activation	0	2
Central sulcus not identified	2	0
Total	12	11

* Two hemispheres studied in one volunteer.

Results

The 12 patients included in the study subsequently underwent craniotomy to remove portions of the temporal or frontal lobes. Nine patients had complex partial epilepsy, 2 had tumors in the frontal lobe, and 1 had a tumor in the temporal lobe. The tumors measured between 3 and 5 cm in diameter. Ten volunteers were studied. The right hemisphere was studied in 6 individuals, the left in 15, and both in 1 volunteer. All MR and functional MR studies were considered technically satisfactory.

All patients and volunteers had pixels in which activation was temporally correlated with the performance of a task. The changes were 2% to 5% of baseline in magnitude and lagged behind the initiation of the task by 3 to 5 seconds. The time course plots in activated pixels had correlation coefficients of approximately .5 to .7. The activated pixels were generally clustered. The few solitary pixels with temporally correlated signal intensity changes were considered artifacts.

The readers identified the central sulcus by the anatomic criteria in the 20 subjects (21 hemispheres), including 1 with a temporal lobe tumor. In the 2 patients with frontal lobe tumors, the central sulcus was not identified on MR, because anatomic landmarks were obscured (Table). In 19 of the 21 hemispheres in which a central sulcus was selected on anatomic criteria, the presumptive central sulcus intersected or contacted the region of activation on the functional MR imaging (Fig 1). In 1 subject the sulcus selected as the central sulcus was located ventral to the activation in the functional MR study (Fig 2); in another subject it was dorsal. In the 2 cases of frontal lobe tumors, be-

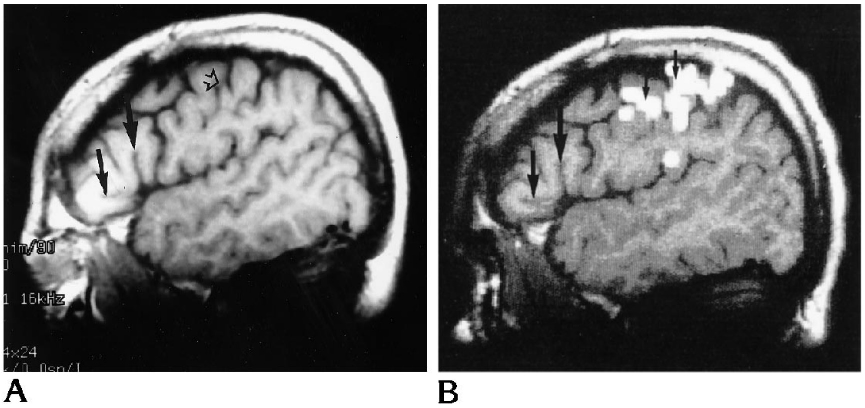


Fig 1. Parasagittal MR image (*A*) and corresponding functional image of the finger movement task (*B*) in a healthy volunteer. Note the anterior ascending and anterior horizontal rami (*arrows*) used as landmarks for the inferior frontal gyrus. The activation in the sensorimotor cortex (*vertical arrows* in *B*) corresponds with the central sulcus (*open arrow* in *A*) selected on the basis of anatomic landmarks.

cause the central sulcus was not identified on the anatomic images, no correlation of activation and presumed central sulcus was possible (Figs 3 and 4). In the 9 cases in which it was performed, intraoperative cortical stimulation confirmed motor activity in the gyri in which functional MR imaging showed activation.

Discussion

This study confirms a previous report that locating the sensorimotor cortex by means of anatomic landmarks in an MR image is difficult or impossible in the presence of a mass lesion (2). Functional imaging supplements anatomic imaging, especially in cases of anatomic distortion or topographic variation. Functional MR imaging, like magnetoencephalography (2), may have applications in neurosurgical planning. Functional MR imaging has the advantages over magnetoencephalography or positron emission tomography of greater availability and anatomic images obtained simultaneously with the functional information.

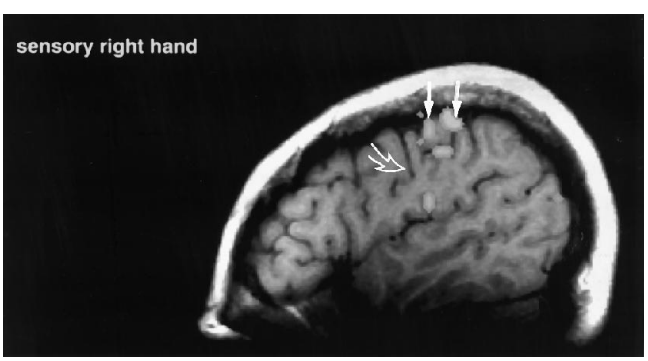


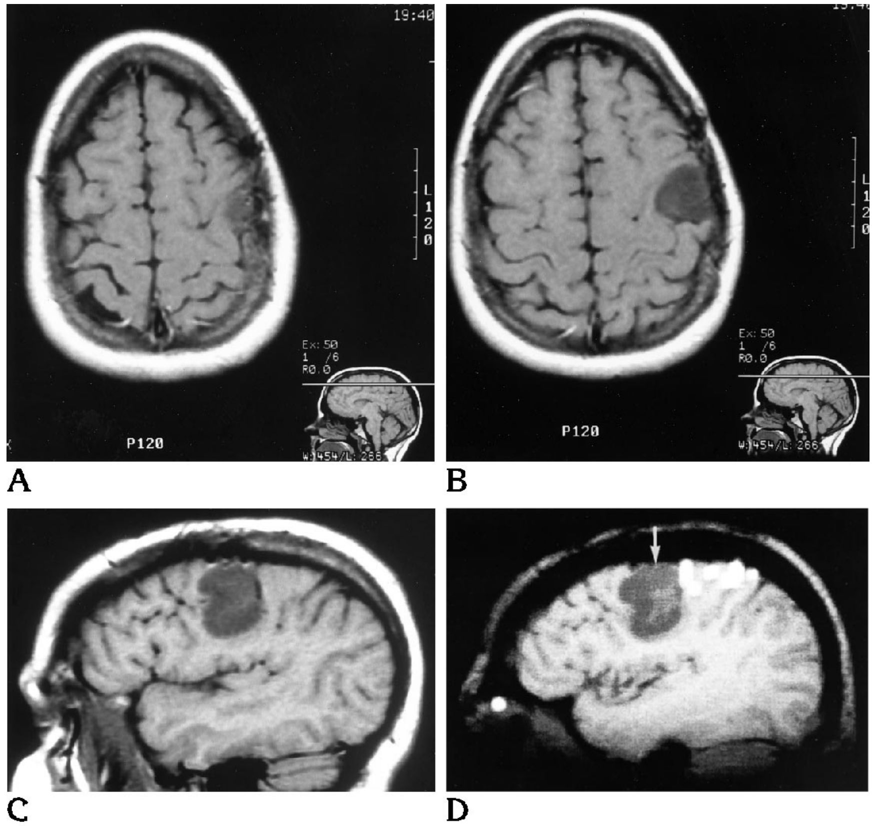
Fig 2. Functional image of finger movement in the sagittal plane shows activation (*vertical arrows*) dorsal to the central sulcus (*curved arrow*).

In our study, the neuroradiologists attempting to identify the central sulcus by anatomic landmarks had only images in the sagittal plane for reference. Their success in identifying the central sulcus may have been marginally higher if they had three-dimensional or supplemental axial images. For identifying the central sulcus, landmarks can be identified on axial images, midline sagittal images, or far-lateral parasagittal images (2, 9, 10). In axial images, the superior frontal sulcus, precentral sulcus, and superior genu of the central sulcus are seemingly reliable landmarks for the rolandic cortex in normal cases. The medial and lateral extent of the central sulcus are also readily identified in a majority of cases. However, tracing the central sulcus through a series of images has been difficult in previous studies (9–11). Three-dimensional surface-rendered images have been useful to trace the central sulcus from the medial to the lateral surface of the brain. In the frontal lobe tumor cases, the central sulcus was no more conspicuous in the region of the tumor on the axial than on the sagittal images.

The criteria for identifying the central sulcus are less reliable in the presence of normal variants. The discontinuity of the inferior and superior portions of the precentral sulcus complicates the identification of the central sulcus (9–12). Differentiating the superior extension of the sulcus from a shallow groove on an adjacent gyrus may be difficult. The lack of convergence of the activation and the central sulcus in two volunteers probably represents inaccurate identification of the superior extent of the precentral sulcus in our cases.

Intraoperative stimulation results suggest that motor and sensory functions do not always have the textbook relationship to the precentral

Fig 3. Axial (*A* and *B*) and parasagittal (*C*) images in a patient with a frontal lobe tumor. The central sulcus was obscured in both axial and sagittal images in the vicinity of the tumor. The functional MR images (*D*) showed activation adjacent in gyri posterior to the tumor (*arrow*).



and postcentral gyri. Some results suggest that the sensory and motor cortex may be a functional unit, with both motor and sensory functions located in each of the precentral and postcentral gyri (2). The location of functions may be altered by plasticity, that is, the process by which neurons in normal regions of the brain take over functions in damaged or diseased brain regions. We did not attempt to distinguish sensory and motor cortices in our study, because activation from the two tasks overlapped in most cases.

In previous studies, functional MR imaging has been used to map the activation secondary to hand movements, visual stimulation, auditory stimulation, and tactile sensation (13–17). In two previously reported studies, the accuracy of functional MR imaging in locating the sensorimotor cortex was verified by comparison with intraoperative mapping techniques (5, 6). In cases in which the location of functions is altered by brain plasticity or reorganization of brain functions, functional MR imaging can identify the location of cerebral function. Functional MR may therefore have a significant role in the selection of patients for craniotomy.

Functional MR imaging has advantages for functional imaging over positron emission tomography or magnetoencephalography. With functional MR, the functional and the reference anatomic images are acquired simultaneously, whereas with magnetoencephalography or positron emission tomography, the anatomic images require a separate acquisition and a method to index the functional to the anatomic

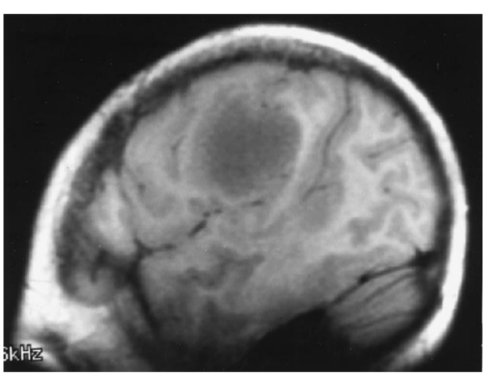


Fig 4. Sagittal MR image in another frontal lobe tumor. The central sulcus was not identified in sagittal or axial images. Activation was identified ventral to this tumor.

images. Functional MR imaging is generally more available than positron emission tomography or magnetoencephalography. Techniques to acquire functional MR at high field strengths, at 1.5 T with echoplanar-image upgrades and with conventional 1.5-T and rapid image acquisition, have been described. Functional MR has better spatial resolution than positron emission tomography or magnetoencephalography and better temporal resolution than positron emission tomography.

This study suggests that functional MR imaging may have a useful role in the preoperative evaluation of patients undergoing craniotomy. In patients with masses that obscure normal cerebral landmarks, functional imaging supplies the information that is not available from the anatomic images. In patients with landmarks that can be recognized, this study shows that the distance between surgical margins and the rolandic cortex are likely to be misjudged in some cases if functional imaging is not used. Determining the risk of a postoperative neurologic defect from surgery is likely to be more reliable with functional imaging than with conventional anatomic imaging. This observation has also been reported by Sobel et al (2) on the basis of magnetoencephalography. Orrison et al (18) have reported that patients considered inoperable because of a presumed close proximity of the rolandic cortex and the cranial tumor have been successfully operated on after functional imaging showed a greater distance between the cerebral lesion and the rolandic cortex than expected. It does not replace intraoperative mapping, which reliably locates the eloquent cortex during surgery, but functional MR might expedite intraoperative mapping by providing a preview. The major contribution of functional MR, however, is that it is a noninvasive method to assess the anatomic relationship of the eloquent cortex to the margins of the lesion during the process of selecting patients for craniotomy.

References

1. Berger MS, Cohen WA, Ojemann GA. Correlation of motor cortex brain mapping data with magnetic resonance imaging. *J Neurosurg* 1990;72:383–387
2. Sobel DF, Gallen CC, Schwartz BJ, et al. Locating the central sulcus: comparison of anatomic and magnetoencephalographic methods. *AJNR Am J Neuroradiol* 1993;14:915–925
3. Rumeau C, Tzourio N, Murayama N, et al. Location of hand function in the sensorimotor cortex: MR and functional correlation. *AJNR Am J Neuroradiol* 1994;15:567–572
4. Colebatch JG, Deiber M-P, Passingham RD, Friston KJ, Frackowiak SJ. Regional cerebral blood flow during voluntary arm and hand movements in human subjects. *J Neurophysiol* 1991;65: 1392–1401
5. Yousry TA, Schmid UD, Jassoy AG, et al. Topography of the cortical motor hand area: prospective study with functional MR imaging and direct motor mapping. *Radiology* 1995;195:23–29
6. Jack JR, Thompson R, Butts RK, et al. Sensory motor cortex: presurgical mapping with functional MR imaging and invasive cortical mapping. *Radiology* 1994;190:85–92
7. Bandettini PA, Wong EC, Hincks PS, Tikofsky RS, Hyde JS. Time course EPI of human brain function during task activation. *J Magn Reson* 1992;25:390–397
8. Hammeke TA, Yetkin FZ, Mueller WM, et al. Functional magnetic resonance imaging of somatosensory stimulation. *J Neurosurg* 1994;35:677–681
9. Naidich TP, Valavanis AG, Kubik S. Anatomic relationships along the low-middle convexity, 1: normal specimens and magnetic resonance imaging. *Neurosurgery* 1995;36:517–532
10. Rademacher J, Galaburda AM, Kennedy DN, Filipek PA, Caviness VS. Human cerebral cortex: localization, parcellation, and morphometry with magnetic resonance imaging. *J Cogn Neurosci* 1992;4:352–358
11. Ebeling U, Steinmetz H, Huang Y, Kahn T. Topography and identification of the inferior precentral sulcus in MR imaging. *AJR Am J Roentgenol* 1989;153:1051–1056
12. Ono M, Kubik S, Abernathey CD. *Atlas of Cerebral Sulci.* Stuttgart: Theime Medical Publishers, 1990
13. Belliveau JW, Kwong KK, Kennedy DN, et al. Magnetic resonance imaging mapping of brain function, human visual cortex. *Invest Radiol* 1992;27:S59–S65
14. Binder JR, Rao SM, Hammeke TA, et al. Functional magnetic resonance imaging of human auditory cortex. *Ann Neurol* 1994; 35:662–672
15. Kim S-G, Ashe J, Hendrich K, et al. Functional magnetic resonance imaging of motor cortex: hemispheric asymmetry and handedness. *Science* 1993;261:615–617
16. Kwong KK, Belliveau JW, Chesler DA, et al. Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation. *Proc Natl Acad Sci USA* 1991;89:5675–5679
17. Rao SM, Binder JR, Bandettini PA, et al. Functional magnetic resonance imaging of complex human movement. *Neurology* 1993;43:2311–2318
18. Orrison WW Jr, Lewine JD, Sanders JA, Hartshoure MF. *Functional Brain Imaging.* St Louis: Mosby, 1995:391