Correlation of motor cortex brain mapping data with magnetic resonance imaging

MITCHEL S. BERGER, M.D., WENDY A. COHEN, M.D., AND GEORGE A. OJEMANN, M.D.

Departments of Neurological Surgery and Neuro-Radiology, and Northwest Neuro-Oncology Research Section, University of Washington Medical Center, Seattle, Washington

Brain maps derived intraoperatively from patients undergoing tumor resection were correlated retrospectively with magnetic resonance (MR) images with respect to the precise localization of the motor cortex in an attempt to identify useful preoperative MR imaging landmarks that correspond to functional brain regions. Superior axial T2-weighted MR images consistently localized the central sulcus, whereas parasagittal and far-lateral sagittal images readily identified the rolandic (sensorimotor) cortex, as a functional unit, based on the cingulate-marginal sulcus and insula, respectively. It is therefore concluded that multiplanar MR images may serve as a useful preoperative planning aid prior to removing intrinsic brain tumors within or adjacent to the motor cortex.

KEY WORDS • brain neoplasm • motor cortex • central sulcus • magnetic resonance imaging • intraoperative mapping

A FEW studies have been published that attempt to correlate diagnostic imaging data, primarily computerized tomography (CT), with functional regions of the brain. This has been accomplished by comparing clinical syndromes to lesions depicted on CT scans, or by correlating anatomical specimens from fixed brains to serial CT slices. Both methods, however, fail to consider the individual variability in functional brain organization. In addition, CT lacks resolution, especially with tumor-associated edema and mass effect, and is unable to provide clear coronal or sagittal reconstructed images that would yield standard reference points for predicting the location of the sensorimotor (rolandic) cortex as it relates to an adjacent mass lesion.

Magnetic resonance (MR) imaging combines multiplanar techniques with precise anatomical details. Utilizing intraoperatively derived brain maps from patients undergoing tumor resection, we attempted to correlate functional data concerning the rolandic cortex with MR scans in the axial, sagittal, and coronal planes. The purpose of this study was to identify useful landmarks on multiplanar MR images that could be used preoperatively to predict the relationship of a tumor to the motor cortex.

Materials and Methods

Multiplanar MR imaging data obtained from nine patients who had previously undergone craniotomy, brain mapping, and resection for intrinsic tumors in the region of the rolandic cortex were retrospectively analyzed. The patients ranged in age from 11 to 55 years and presented with seizures and/or sensorimotor deficits.

The MR images were obtained using a 1.5-tesla magnet in eight patients and a 0.5-tesla magnet in one patient. Imaging sequences consisted of sagittal T2-weighted images (TR 600 msec, TE 20 msec) and axial T2-weighted images (TR 2500–2700 msec, TE 80 msec). All scans were performed prior to the availability of the gadolinium contrast agent. The tumor nidus was identified in regions with abnormal signal intensity and alteration of the typical configuration of cortical and subcortical anatomy as compared with the corresponding images in the uninvolved hemisphere.

All patients underwent intraoperative brain mapping while awake or under general anesthesia, depending upon the relationship of the tumor to the dominant cerebral hemisphere. The technique of electrical stimulation mapping used in our patients has been described
FIG. 1. Case 1. Left: $T_2$-weighted high-vertex axial magnetic resonance image showing the central sulcus, depicted as two mirror-image lines (hyperintense) nearly perpendicular to the midline. The left motor cortex is involved with tumor (T) and lies directly in front of the central sulcus. Right: Intraoperative brain map with the primary motor cortex labeled 1 to 5. Number 17 overlies the tumor which occupies the motor cortex.

previously by Ojemann, et al. Briefly, the cortex is directly stimulated with a bipolar electrode using a train of constant-current biphasic square-wave pulses (60 Hz). The current that is necessary to elicit the desired motor movements varied between 2 and 16 mA, depending upon whether the patient was awake (lower current) or asleep. Numbers are placed on the cortical surface that correspond to a specific motor movement, and a photograph is taken prior to and following resection and stored with the schematic drawing of the patient’s brain map. Dimensions of the mass were obtained based on the abnormal surface configuration and the intraoperative ultrasound characteristics of the tumor. The dimensions determined included the anteroposterior and mediolateral distances, the depth, and the relationship of the lesion to the location of the motor cortex, including the premotor and central sulcus. The MR images were then compared to the intraoperative brain maps on an individual basis, and anatomical landmarks on the three different MR planes.

FIG. 2. Case 2. Left: $T_2$-weighted high-vertex axial magnetic resonance image. The central sulcus is readily identified (mirror-image lines perpendicular to the midline), and the left motor cortex (M) is clearly not involved with tumor (T). Right: Intraoperative brain map with the motor cortex labeled 1 to 6. The tumor occupies the supplementary motor cortex (numbers 22 and 23) and appears as an expanded gyrus.
were correlated with the previously defined functional cortical regions.

Results

The rolandic cortex was most reliably identified on the most rostral vertex T$_1$-weighted axial MR images. The central sulcus was clearly defined as a mirror-image pair of distinctly transverse sulci. The primary motor cortex was always located directly anterior to this sulcus, which was preserved irrespective of imaging angulation or mass effect from the tumor (Figs. 1 and 2). The central sulcus was not as readily defined on the sagittal or slightly parasagittal midline sections (T$_1$- or T$_2$-weighted sequences); however, the rolandic cortex could be identified as a unit as the gyri directly anterior to the marginal sulcus which is the terminal continuation of the cingulate sulcus seen only in this MR plane (Figs. 3 and 4).

When the tumor extended further laterally, the rolandic cortex could be identified as a unit when related to the insular triangle. A line is drawn perpendicular to the posterior roof of the insula, and this demarcation consistently passed through the region of the rolandic cortex. This was the least accurate plane on which to localize the motor cortex directly; however, it routinely identified the sensorimotor unit. This MR plane was also most affected by an accompanying mass effect, which in some cases shifted the rolandic cortex directly in front of or posterior to the perpendicular insular line (Figs. 5 and 6).

Discussion

The lack of resolution obtained with CT scans in depicting the central sulcus has made it difficult using this modality to consistently identify motor cortex in most patients based on traditional concepts of neuroanatomical localization of the primary motor area (Brodman area 4). Reformatted sagittal and coronal views are particularly unclear in terms of sulcal and gyral delineation. However, multiplanar images using MR techniques provide unparalleled detail and allow for clear comparison of intra-axial lesions to consistent sulcal landmarks. Using pictures of brain maps from patients undergoing tumor removal following direct cortical stimulation, we were able to retrospectively correlate the primary motor area with reproducible MR imaging anatomy in our patient population.

Due to the variability of language localization noted in our patients and in other reported series, we did not attempt to correlate MR imaging landmarks with functional language cortex. Although this has been attempted by comparing lesions seen on CT and function recovery time following the onset of language deficits, the lack of specific language regions prevents this from becoming a useful preoperative planning technique.

The central sulcus and the precentral (motor) gyrus were accurately identified in all of our cases by localizing the pair of transverse (central) sulci easily seen on high-vertex axial images. Even though parasagittal and far-lateral sagittal planes were less likely to localize the central sulcus, the rolandic cortex could be readily identified and served as a very useful preoperative guide toward understanding the relationship between the intrinsic tumor and functional cortex. The marginal sulcus and insula are stable MR imaging landmarks, and can be located regardless of local mass effect from the tumor. We have subsequently used this retrospective

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**FIG. 3.** Case 1. Parasagittal T$_1$-weighted magnetic resonance image. The cingulate sulcus is seen as a hypointense signal that ends superiorly as the marginal sulcus (X). The rolandic cortex is directly in front of this sulcus and is partially occupied by tumor.

**FIG. 4.** Case 2. Parasagittal T$_1$-weighted magnetic resonance image. The terminal end (X) of the cingulate sulcus demarcates the rolandic cortex (M = motor, S = sensory). The tumor (T) was located in the supplementary motor cortex.
information to plan surgical approaches for any cortical or subcortical lesion and to decide if intraoperative mapping will be necessary depending upon the extent of resection desired.

Acknowledgment

The authors express their appreciation to Marilyn J. Happs Brink for editorial assistance.

References

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Manuscript received June 19, 1989.