Preoperative Mapping of the Supplementary Motor Area in Patients with Medial Frontal Lobe Brain Tumors

L. A. Nelson[1], S. Lapsiwala[2], V. M. Haughton[3], J. Noyes[4], A. Sadrzadeh[5], C. H. Moritz[6], B. Badie,[8] M. E. Meyerand[7]

Departments of Radiology[1,3,6] Medical Physics[7],and Neurological surgery[2,4,8] University of Wisconsin, Madison, WI.

Abstract

Injury to supplementary motor area (SMA) causes transient motor and speech deficits following resection of tumors involving the medial frontal lobe. We hypothesized that functional MRI (fMRI) may be useful in predicting the risk of postoperative deficits in patients undergoing resection of tumors in this region. The risk of developing either a postoperative speech or motor deficit was 100% when the distance from the center of mass of SMA activation to the tumor margin was 5 mm or less; when the distance was greater than 5 mm, the risk of either a motor or speech deficit was 0% (p=0.0007).

Introduction

The supplementary motor area (SMA) is thought to play a key role in initiation and control of motor and speech functions(4). Lesions of the SMA produce characteristic neurological deficits (6, 7). Severe expressive aphasia, mutism and immediate hemiparesis contralateral to the affected hemisphere have been reported following removal of tumors involving the SMA (2, 6, 7). Most patients fully recover from SMA injuries, but some may have long-lasting disturbance of fine motor skills and complex speech functions. Because of the associated neurological deficits, identification of the SMA location may be helpful in minimizing injury to this area during neurosurgical procedures. Functional magnetic resonance imaging (fMRI) has been used in the preoperative identification of eloquent brain cortex prior to surgical excision of brain tumors (1, 3). Upon execution of motor and speech tasks, activation in both SMA proper and pre-SMA can be detected with fMRI (5). To our knowledge, the efficacy of fMRI in predicting the risk of SMA injury prior to tumor excision has not been examined in detail. The purpose of this study was to evaluate the fMRI activation of the SMA in patients with frontal lobe tumors and more specifically, to test whether the distance between the tumor margin and SMA activation correlates with the risk of postoperative neurological deficits.

Methods

Twelve patients with frontal lobe tumors involving the SMA were included in the study. Preoperative fMRI using language and motor tasks were obtained in every patient to localize the SMA. Patients with tumors involving the insular cortex, sensorimotor cortex, or Broca's area were not included. Scanning was performed on a clinical 1.5T magnet equipped with high-speed gradients for whole-body echo planar imaging (EPI). EPI fMRI scanning was acquired in the coronal plane using 20 slice locations, 6mm-thick slices with a 1mm skip, providing approximately whole brain coverage. Expressive language function was assessed by having the patient perform an antonym word generation task (AWG), letter word generation (LWG) task, or both during a fMRI scan. The patient performed either a finger tapping, foot movement paradigm, or both during an fMRI scan involving alternating blocks of either right or left limb activity interleaved with periods of rest. Functional MRI maps were derived by cross correlation to a smoothed boxcar reference function modeling the presumed hemodynamic response for the task performance using a generalized least squares fitting algorithm and provided a t statistic functional activation map ($p > 0.005$) that was overlaid on the co-registered anatomical brain volume. Any activation in the superior frontal gyrus along the midline within the following anterior/posterior, superior/inferior, and lateral boundaries was considered SMA: anteriorly, 20mm in front of a line drawn perpendicular to the AC-PC line at the anterior commissure; posteriorly, by the central sulcus; inferiorly, by the cingulate gyrus; and laterally, by the superior frontal sulcus. For each task the center of mass (COM) of an activation cluster within SMA was determined by the 3D clustering method. In patients with gliomas, the distance from the edge of the region with low signal intensity on a T1-weighted image to the COM of activation was calculated. Patients' medical charts were reviewed for pre-operative, and post-operative motor and language deficits with the temporal course and neurological character of an SMA injury and were rated for severity. McNamar's Test was applied to test the interdependence of the motor and speech tasks. Fisher's exact test was then used to compare the significance of the distance between SMA and the tumor margin to the risk of postoperative deficits in the combined motor and speech groups (24 cases total).

Results

Twelve patients were identified in the study period including 11 patients with gliomas and one patient with an atypical meningioma. In this group, two patients with postoperative speech deficits and two patients with postoperative motor deficits were identified that met the criteria for an SMA injury. One patient had both a motor and a speech deficit. Speech SMA activation was located in the left hemisphere in the majority of patients and was bilateral in two patients. The patients who did not develop postoperative aphasia included four patients with a distance of greater than 5 mm between the tumor edge and the SMA language activation and six patients with SMA activation located in the hemisphere contralateral to the tumor. These findings suggest that close proximity of SMA, as detected by fMRI, may be important in predicting postoperative speech deficits in patients with medial frontal lobe tumors. In addition to the primary sensorimotor cortex, motor tasks resulted in the activation of the contralateral SMA in most patients. Two of the 12 patients had a distance of less than 5mm between the tumor edge and the COM of the ipsilateral SMA motor activation cluster. Both patients had transient post-operative motor deficits typical of an SMA injury. Interestingly, patient 1 who developed speech problems after surgery did not exhibit any motor weakness. Although the SMA activation following speech tasks was located adjacent to the tumor, his motor SMA activation with motor tasks involving either hand was located in the opposite hemisphere (Figure 1). This contralateral motor SMA activation, most likely, explains why this patient did not develop any weakness after tumor resection.

Discussion

In the present study, the SMA was identified reliably in every patient and a distance of 5mm between SMA activation and the tumor margin was correlated with postoperative motor and speech deficits. There is evidence of plastic reorganization in three patients with either ipsilateral or bilateral SMA activation with motor tasks that involved the limb opposite to the tumor, which suggests that SMA location cannot be predicted solely on anatomic landmarks in patients with medial frontal lobe tumors. Since most patients recover from SMA injuries, prospective analysis of these patients with fMRI may provide an interesting model to study brain plasticity as it relates to SMA function.

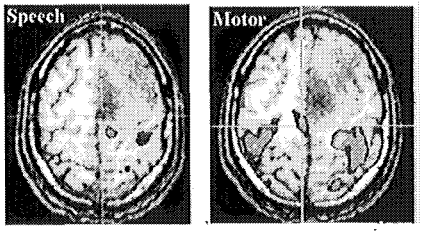

Figure 1. fMRI images for the speech task (A) and motor task (B) are shown for Patient No.1 with a Grade III astrocytoma. The COM for SMA activation secondary to the motor task lies 0 mm from the edge of the tumor; and for the speech task (B) lies 2.7 mm from the edge of the tumor. The patient exhibited a transient mild aphasia and no motor deficit.

References

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