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Commentary

The Central Sulcus and Surgical Planning

Richard D. Bucholz[1]

Functional imaging soon will become as important as anatomic imaging in presurgical planning. Anatomic imaging, such as computed tomography (CT) and magnetic resonance (MR), have greatly enhanced the ability of a neurosurgeon to detect and safely resect intracranial lesions. Intraoperative locating devices, such as optical digitizers, have effectively coupled these imaging advances to the actual performance of surgery.

Equally as important as the ability to detect and remove a lesion is the avoidance of areas of the brain that orchestrate specific functions, termed "eloquent" cortex. The location of eloquent cortex has been well documented in healthy individuals, but intracranial lesions often distort the normal architecture by mass effect and cerebral edema. A surgical path to a deep-seated mass which would avoid eloquent cortex in a normal brain may result in a massive neurologic deficit because of shift caused by the lesion itself.

The changing nature of neurosurgery also will increase interest in functional imaging. Many investigative procedures aim to restore function rather than simply to resect lesions. Although functional neurosurgery has been performed for decades, its broad acceptance has been limited by the inability to image function. As our ability to restore function improves, with surgery for epilepsy, transplant surgery, functional lesion surgery, brain stimulators, and drug polymer implants, our need to detect abnormal function will increase.

A variety of technologies have been used to image the brain functionally. Positron emission tomography (PET), single photon emission CT (SPECT), magnetoencephalography (MEG), and functional MR imaging (FMR) are all capable of detecting the anatomy of function. These techniques can be evaluated by multiple criteria, including cost and whether function is being detected directly or simply inferred by the detection of changes in metabolism. PET, SPECT, and FMR are capable of showing changes only in oxygen metabolism, blood flow, or blood volume, and therefore do not directly detect function. Although these techniques have other attributes, their theoretical resolution, so important to the surgeon in planning, always will be inferior to a direct technique given the geographic spread of metabolic changes incurred during function. MEG is one of the few modalities that can directly detect the signal emanating from functional activity as it records the magnetic impulse produced during activation of the cortex. Only neurophysiologic methods, such as evoked potentials or direct cortical stimulation, share this ability to measure directly the signal emanating from activity. The main advantage of MEG compared with electrophysiologic methods is that is does not suffer from spatial distortions produced by the insulating bone, which degrades the accuracy of scalp electrical recordings.

Soebel et al (1) in this issue of *AJNR* demonstrate the accuracy of MEG. In healthy subjects the concordance of location of the central sulcus (CS) by MEG and by multiple MR techniques was excellent. More important for surgical planning, MEG had a better correlation with intraoperative somatosensory (SSEP) recordings than did any of the MR techniques, which became quite subjective in the presence of shift and edema. The error of the MR techniques was proportional to the degree of shift and the proximity of the lesion to the CS. The exact accuracy of MEG could not be determined in this series, as there was no means available to register the intraoperative SSEP recordings to the MEG data.

We have had experience with eight patients who have undergone both MEG and intraoperative SSEP recordings during surgery performed

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with the aid of an intraoperative location device. The patients included in this protocol all harbored tumors close to the CS. Intraoperative location was performed using an optical digitizer, which tracks surgical instruments equipped with light-emitting diodes continuously during surgery (2, 3). A work station displays position on axial, coronal, and sagittal reconstructed CT, MR, or PET images. MEG data can be registered using the nasion and preauricular fiducial points, as indicated in the paper by Soebel et al. Intraoperative SSEP and motor studies were performed, and the position of maximal response related to the MEG studies.

We have found excellent correlation between MEG and SSEP data in our series, with an error of less than 11 mm. MEG has been reliable and useful when performing surgery near the CS by demonstrating the position of eloquent cortex and allowing the surgeon to alter the surgical path and avoid damage to these critical areas. The CSs of many of our patients were shifted to areas that normally would have been expected to be silent and therefore resectable.

Our major difficulty in evaluating MEG has been the inaccuracy of intraoperative neurophysiologic techniques. Cortical responses are recorded using electrodes separated by a minimum of 1 cm, making the exact locus of activity difficult to find with precision. A major challenge to the acceptance of MEG is the identification of a suitable standard that precisely identifies the locus of function for comparison to MEG. The actual resolution of MEG is limited only by the number and separation of the detectors, which are currently quite expensive. Continued development of high-temperature superconducting alloys holds the promise of lowering the cost of these detectors. MEG has several disadvantages, the most notable being cost. Although the detector cost may respond to new technologic developments, shielded rooms will still be necessary, and it is doubtful that this technology will ever become as widely disseminated as CT or MR. Furthermore, as MEG does not actually image the brain but rather locates function, a concomitant MR is needed, upon which the origin of magnetic impulses are mapped. The accuracy of the technology is therefore limited by the errors incurred in the process of registration to MR images, and from the spatial distortion inherent in MR. Finally, there are only a few protocols currently developed for simple motor and sensory functions. Complex tasks, such as speech and audition, have not been detected reliably with this technology.

Although the applications of functional imaging are numerous, many questions must be resolved before informed decisions to implement this costly technology can be made. The accuracy of each technology must be assessed. The development of higher resolutions by decreasing voxel size many be necessary before a technique can become clinically useful. The process of registration to anatomic images has to be simplified and accuracy improved, either through contour mapping or stereotactic techniques. It is also critical to develop additional paradigms to locate other neurologic functions.

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