Magnetic source imaging: a future in CNS evaluation?

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Commentary

Magnetic Source Imaging: A Future in CNS Evaluation?

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Minute magnetic fields produced by neuronal activity within the brain can be recorded with highly sophisticated detector systems over the intact surface of the skull. Analysis of these fields, which directly reflect functional activity of the brain, affords the opportunity for evaluating the CNS in a manner unfamiliar to most clinicians and radiologists. The preceding article by Orrison et al. [1] describes how such techniques can be used to localize specific functional areas of the brain and how this information can be combined with standard MR images. The resulting montage of information, which aptly can be called a *magnetic source image* (MSI), is intriguing because it combines structure and function within an image. The important issue, however, is whether it may have a future in CNS evaluation.

Electroencephalography (EEG) is currently the standard technique for evaluating the electrical activity of the brain. Although it is effective and has withstood the test of time, EEG has well-known shortcomings; the electrical signal that is recorded by means of electrodes in contact with the scalp is distorted significantly by its passage through the inhomogeneities of brain, CSF, skull, and scalp. As a result, localization of the precise source of the brain electrical activity, whether normal or abnormal, generally is thought to be rather inexact. On the other hand, the magnetic field generated by neuroelectric activity passes through the brain, CSF, skull, and scalp essentially unimpeded, so in theory MSI should localize sources of neural activity more accurately than EEG techniques.

The difficulty with recording brain magnetic fields at the surface of the scalp, however, is that the fields are extremely small (on the order of 10^{-6} to 10^{-9} of the earth's magnetic field) and are measured in units of femtoTesla (10^{-15} T) or picoTesla (10^{-12} T). Sophisticated instrumentation that uses superconducting technology is required to record such fields. The system required to measure the magnetic fields generated by the brain has been termed *magnetoencephalography*, or MEG. A biomagnetometer, which is the instrument used to measure the MEG, has niobium detection coils immersed in liquid helium, all of which are contained within a specially designed Dewar flask. The flask allows the detection coils to be positioned within 2 cm of the scalp surface. Electric currents induced in the detection coils by magnetic fields of the brain are coupled to a sensitive magnetic-field amplifier known as a superconducting quantum interference device (SQUID), which produces an electrical current proportional to the magnetic fluctuations. Such signals are amplified and analyzed, yielding temporal and spatial measures of the underlying neural activity. The principles and techniques not only are applicable to the CNS but also are germane to neuromuscular and cardiac applications.

Figure 1A (left panel) shows the temporal variation in the magnetic field at two points over the right temporal scalp of a normal subject being stimulated by auditory tones. This waveform reflects activity of the primary auditory cortex for more than 500 msec after an auditory stimulus presented at the 0-msec point on the x-axis. The magnetic field shows characteristic variations according to the location over the scalp where it was recorded. Figure 1A (right panel) also shows the isocontour plot of the magnetic field corresponding to the peak of the initial evoked field peak, the so-called N100m peak. The contour plot of the generated magnetic field shows the magnetic field exiting the skull at one point and entering at another. These two regions (the extrema) represent the areas of maximal strength of the scalp-recorded magnetic field and can be used to calculate where in the brain the electrical source of the magnetic field lies by using the

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This article is a commentary on the preceding article by Orrison et al.

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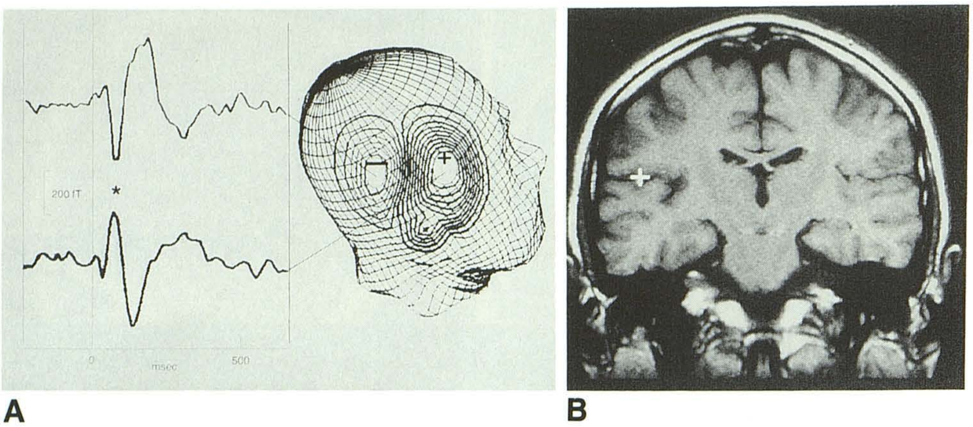

Fig. 1.—*A*, *Left panel* shows temporal waveform of auditory evoked field recorded from two positions over right temporal scalp of a normal subject. A brief auditory stimulus (a 50-msec 100-Hz tone burst) was presented at 0 msec, and the magnetic-field activity was recorded for more than 500 msec after the stimulus. Averaging techniques were used to increase signal-to-noise level of recordings. *Right panel* is isocontour plot of magnetic-field distribution over right hemisphere corresponding to peak of prominent evoked field component having a latency of approximately 100 msec. Asterisk = N100m. Regions of maximum magnetic flux are labeled + (exiting flux) and − (entering flux).

B, Calculated location (+) for a current dipole source that can produce the pattern of magnetic flux shown in *A* is superimposed on corresponding MR image for the subject.

Figure by courtesy of Biomagnetic Technologies, Inc., San Diego, CA.)

model of a current source dipole. The dipole source lies midway between the extrema and at a depth proportional to the distance between the extrema. Thus, by recording the magnetic field over the skull at multiple sites, it is possible to localize the theoretical source of the activity as well as its strength and orientation within the brain.

Figure 1B shows the localization of the dipole source calculated on the basis of the contour maps of Figure 1A superimposed on the appropriate MR image for the subject. This superimposition of functional and anatomic information can be termed *magnetic source imaging* (MSI). As shown, the primary activity reflected in the auditory evoked magnetic field has its origin in the appropriate auditory area of the temporal lobe. Such functional mapping techniques can be applied to other sensory modalities, such as vision and somatosensation, and in the future may be applied to motor activation and higher cognitive processes.

Aside from the physical principles involved and the integration of standard neuroradiologic imaging with these magnetic-field data, the issues of siting, equipment, and problems with MEG deserve comment. In the past, MEG suffered because data collection was extraordinarily time-consuming, since only single-channel devices were available. Systems, such as that used by Orrison et al., have seven detector coils, which decrease recording time. Newly introduced systems have 37 channels covering an area of more than 160 cm^2 of the scalp, allowing adequate data to be collected in minutes, depending on the application. This begins to bring MSI into the realm of medical reality. Siting for the equipment requires space for a magnetically shielded room and the associated computer system, which is generally not a problem for an urban medical center.

The cost of MEG is difficult to pinpoint because the technique and equipment are new and the eventual level of clinical acceptance is unknown. It is estimated, however, that the large-scale (37 channel) system and its siting will cost about the same as an MR system. In addition to these economic considerations, issues related to scanning patients and interpreting images are of concern, and standards will have to be developed.

These observations notwithstanding, it appears that the potential for MEG and its integration with routine imaging (i.e., MSI) is considerable. A major advantage of this technique is its ability to detect changes in electrical activity instantaneously. The result of an auditory or visual stimulus, for example, can be recorded with a resolution of milliseconds, which is many magnitudes of order faster than similar metabolic responses seen with positron-emission tomography. Because mapping out normal and abnormal cortical activity without the need for surface or depth electrodes is possible with this technique, clinical applications are therefore numerous and potentially revolutionary.

The most obvious clinical application of MSI is in the area of seizure disorders; however, evaluation of dementia, drug efficacy, psychiatric disorders, and evaluation of learning disabilities may be fruitful areas for investigation. The study of these problems is particularly exciting because such disorders have been elusive or invisible when routine imaging techniques have been used. Abnormally strong magnetic fields (five to 20 times the strength of a normal brain) during seizure activity and characteristic magnetic potentials during interictal periods can be detected and localized. The mapping of sensory evoked potentials in cortical and subcortical abnormalities and the evaluation of the processing of sensory information in neuropsychiatric disorders are also possible.

In order to extract the maximal information and clinical relevance and eventually to further patient care, magnetic-field information should be related carefully to specific anatomic structures as seen on MR and CT. MSI may become a new challenge for neuroradiologists in the 1990s and beyond.

ACKNOWLEDGMENT

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REFERENCE

1. Orrison WW, Davis LE, Sullivan GW, Mettler FA Jr, Flynn ER. Anatomic localization of cortical function by magnetoencephalography, MR imaging, and CT. *AJNR* **1990**;11:713–716