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Magnetoencephalography Aids Diagnosis and Treatment of Epilepsy, Other Disorders

- Magnetoencephalography can detect neuronal activity noninvasively by measuring the magnetic fields surrounding the human head.
- The technique is typically used for neuroscience studies and increasingly for presurgical evaluation and surgical planning in epilepsy patients.
- Emerging applications include schizophrenia, autism and traumatic brain injury diagnosis.

Orginally used only for research purposes, magnetoencephalography (MEG) has been introduced into clinical care in recent decades. With applications in epilepsy already benefiting from its use, and still others on the horizon, the technique is helping to advance diagnosis and treatment for a range of diseases, disorders and injuries.

What is Magnetoencephalography (MEG)?

Magnetoencephalography records disruptions in the very weak magnetic fields surrounding the human head that are caused by electrical activity associated with neuronal currents underlying brain function. The technique offers excellent temporal resolution—on the order of milliseconds—and thus provides a more direct measure of neuronal currents than other imaging modalities, including functional magnetic resonance imaging (fMRI), which derive information about neuronal activity from the much slower neurovascular response.

The technique was introduced nearly 50 years ago by MIT researcher David Cohen, who is now a faculty member at the Athinoula A. Martinos Center for Biomedical Imaging in the Department of Radiology at Massachusetts General Hospital. Cohen developed a way to isolate and record the weak magnetic fields emanating from the human body by using a magnetically shielded room built around the recording equipment. On New Year's Eve 1969, using a superconducting quantum interference device (SQUID) developed by James Zimmerman while he was a researcher working with the Ford Motor Co., Dr. Cohen successfully recorded the biomagnetic signal from Dr. Zimmerman's heart. He later applied the technique to the brain, facilitating use of MEG for a range of neuroscience studies.

In the early days of MEG, researchers used either one or several magnetometers to localize electrical activity in the brain. Because these measurements used so few sensors and allowed only small coverage of the brain, researchers had to obtain recordings from multiple locations on the head, making the procedure impractical for routine clinical use. Later, researchers introduced multi-channel MEG systems with coverage of up to 12 cm—enough to localize activity in a registered MRI scan of the brain, opening the door to clinical application.

With hundreds of channels providing whole-head coverage, modern MEG systems enable an array of applications that require mapping of activity throughout the cerebral cortex. Today there are roughly 60 clinical MEG systems in the world. The system at Mass General, located at the Martinos Center on the hospital's research campus in Charlestown, MA, is the only MEG system in the New England region.

Clinical Applications of MEG in Epilepsy Patients

Noninvasive neuroimaging with MEG is most widely used clinically for presurgical evaluation and surgical planning in epilepsy patients: for localizing epileptic discharges, determining the language-dominant hemisphere and mapping the eloquent cortex. Here, MEG is often combined with MR imaging, which provides structural guidance for the recordings.

Figure 1. Long used for neuroscience studies, the neuroimaging technique magnetoencephalography (MEG) has in more recent years gained entry into the clinic, where it is widely used for presurgical evaluation and surgical planning in epilepsy patients. Shown here, two volunteers demonstrate use of the MEG scanner at Mass General. *(Photo courtesy of Matti Hämäläinen, Athinoula A. Martinos Center for Biomedical Imaging at Massachusetts General Hospital)*

By localizing epileptic discharges, MEG helps identify the sources of seizures through analyses of spontaneous brain activity. Measurements are typically performed during rest using whole-head MEG combined with electroencephalography (EEG), a closely related method that provides complementary information about electrical activity in the brain.

After a decision is made to remove the tumor or other lesion responsible for the seizures, MEG can map the eloquent cortex to help avoid functional deficits as a result of surgery. A critical use is determining the language-dominant hemisphere of the brain. This measurement is particularly important for patients scheduled for a left anterior temporal lobectomy (ATL), a widely used procedure for medial temporal lobe epilepsy. Such lateralization is vital for preserving quality of life as verbal memory and language can be impacted by ATL.

Beyond determining the language-dominant hemisphere, clinicians use MEG to delineate the language cortex and other areas of the eloquent cortex (*e.g.,* motor and visual) to outline the regions they want to avoid during resection. The technique can localize both receptive and productive areas with high temporal resolution; the measurements are often combined with fMRI data to improve spatial resolution. Studies have shown that presurgical evaluation of epilepsy patients with MEG leads to improved outcomes in these patients, with greater surgical success and fewer postsurgical deficits.

Emerging MEG Applications: Schizophrenia, Autism and Traumatic Brain Injury

While presurgical evaluation in epilepsy is the primary clinical application of MEG, new applications are emerging. One application is aiding in the diagnosis of schizophrenia. Historically, diagnosis of schizophrenia was based on clinical assessment and evaluation of patients' self-reported experiences, especially as their symptoms become more evident over time. Seeking a more objective measure, clinicians turned to MEG to identify biological markers of the disease such as differences in functional network activity. In recent years, they have explored multimodal imaging, including MEG and fMRI, to provide important classification information that may not be accessible with just one modality.

Applications in autism and traumatic brain injury (TBI) are also on the horizon. While researchers have long known that autism has a neurodevelopmental basis, the actual pathology has remained elusive. Now, using MEG, they have identified electrophysiological biomarkers of the disorder, which can help diagnosis and prognosis as well as contribute to the development of pharmaceuticals for treatment. Similarly, while diagnosis of TBI has been

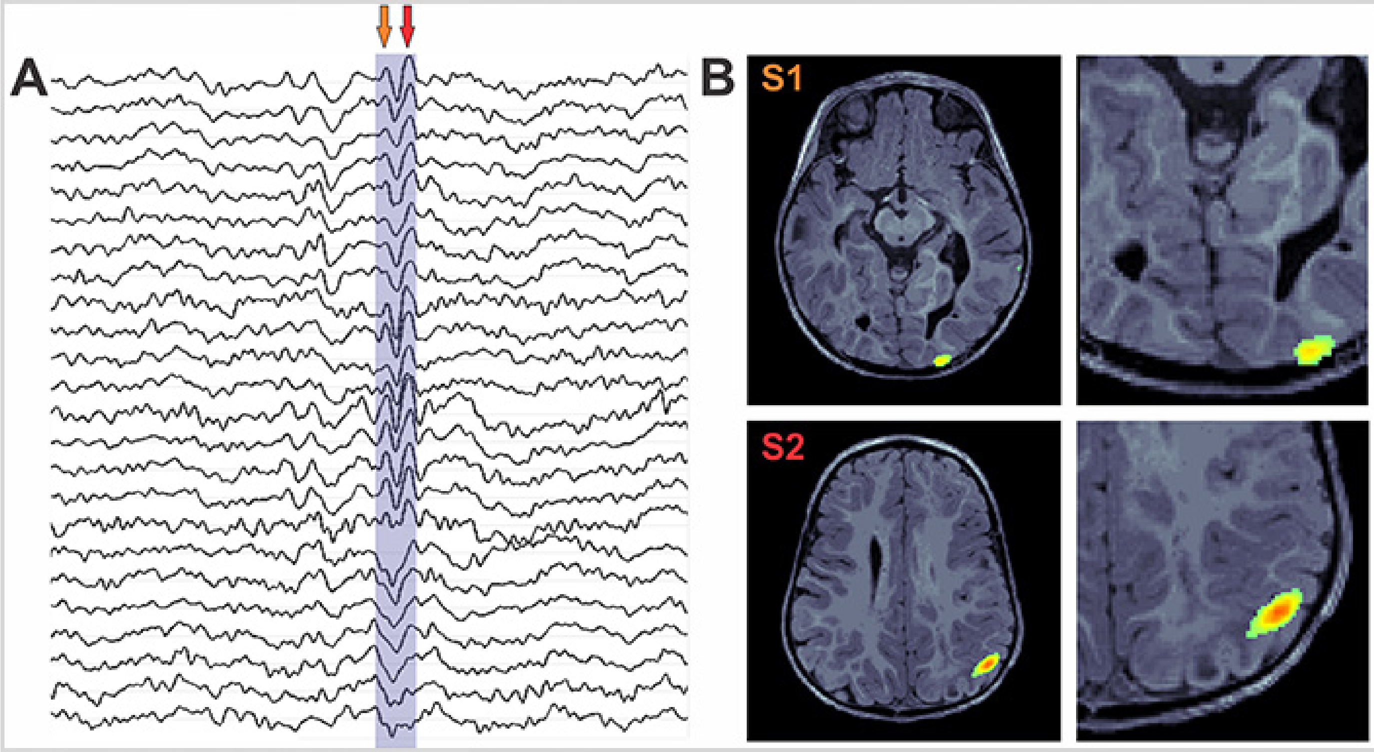

Figure 2. Shown here **(A)** are MEG traces from an epilepsy patient with the epilepectic spikes highlighted. In **(B)**, the MEG activity is overlaid onto a structural MRI scan of the patient's brain. Image courtesy of Sheraz Khan, Athinoula A. Martinos Center for Biomedical Imaging at Massachusetts General Hospital (Khan S, Lefèvre J, Baillet S, et al. (2014). *Encoding cortical dynamics in sparse features*. Front Neurosci **8**: 338.)

challenging, MEG has shown promise for detecting differences in electrophysiological signals between healthy subjects and TBI patients in both military and civilian settings. In addition to diagnosis of TBI, MEG is widely used for neuroscience studies seeking to understand the sequalae of the injury.

Scheduling Clinical Epilepsy MEG Scans

Clinical MEG scans for patients with surgical epilepsy are performed at the Athinoula A. Martinos Center for Biomedical Imaging in the Department of Radiology at Massachusetts General Hospital in Boston. Orders can be placed by an epileptologist or neurosurgeon by emailing Nao Matsuda nao@mgh.harvard.edu or faxing +1 (617) 643-4157.

Further Information

For more information about clinical MEG scans, please contact Steven Stufflebeam, MD, Director of Clinical MEG, Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital. We would like to thank Dr. Stufflebeam for his advice and assistance in preparing this article.

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