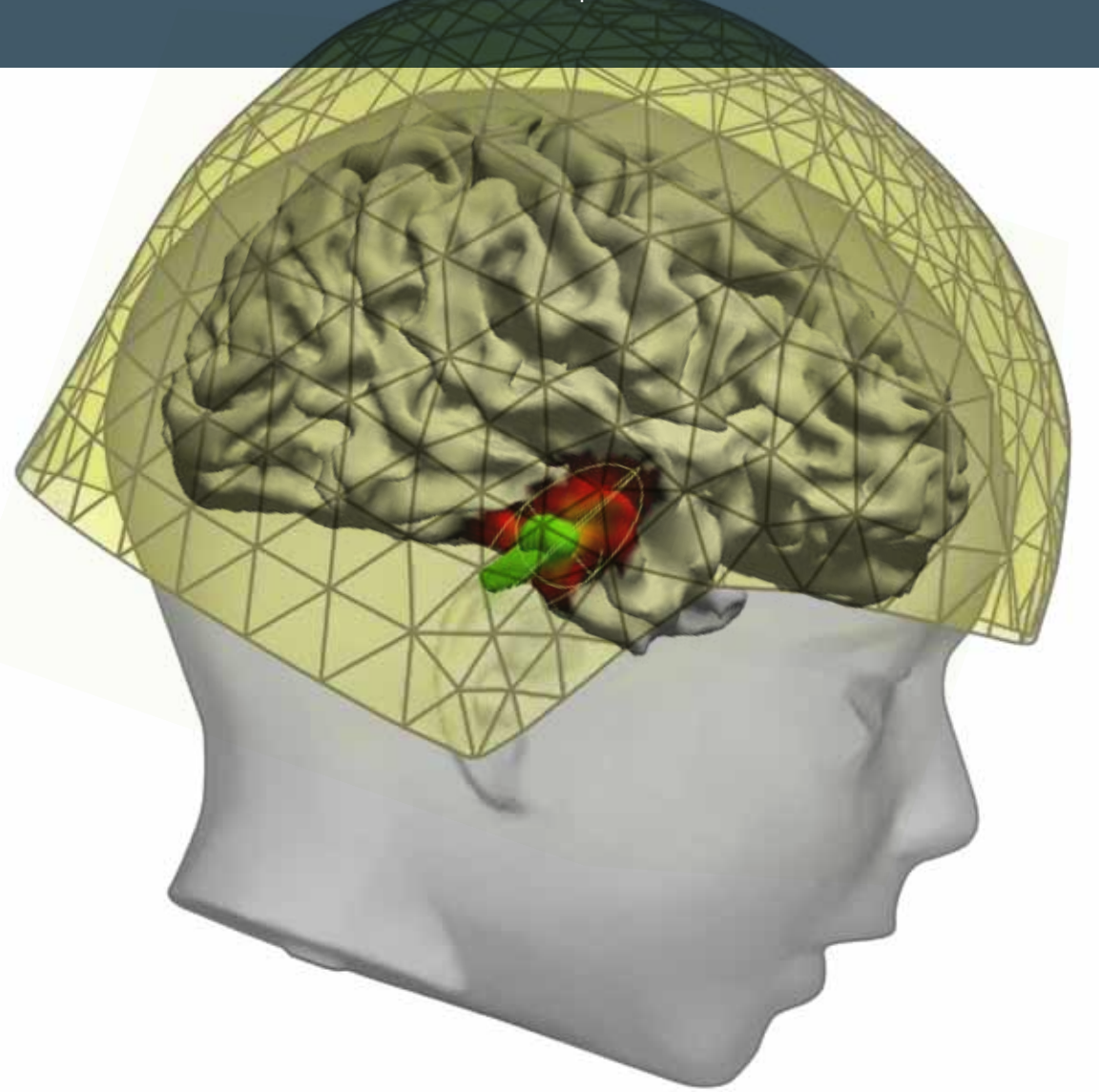
Cleveland Clinic

MEG: Magnetoencephalography

Advanced Brain Analysis Technology

NEUROLOGICAL INSTITUTE | EPILEPSY CENTER



Sensors in the MEG helmet measure magnetic fields generated by rapid changes of electrical activity in brain cells.

A MEG scan is noninvasive, painless and safe for all ages, with no injections, radioactivity or strong magnetic fields.

What Is Magnetoencephalography?

Magnetoencephalography (MEG) is the newest, most advanced method of recording and evaluating the brain while it is actively functioning. This recording provides a direct measurement of the ongoing function of normal neurons and can pinpoint the location of malfunctioning neurons. MEG can be used either to evaluate the brain's spontaneous activity (e.g., for epilepsy) or to check its response to specific external stimuli (e.g., for mapping motor and sensory areas, language, vision and other functions).

MEG can localize epileptic activity more accurately than any other noninvasive modality can, without the smearing and blurring that affect the electroencephalogram (EEG). Due to a very large number of sensors as well as the absence of any effect from skull or scalp, MEG has an inherently high resolution. When we combine MEG with the high-resolution anatomic images obtained via MRI, we can localize the neuronal activity to a specific sublobar area, usually to a specific gyrus or sulcus.

How MEG Works

Brain cells interact by generating tiny electrical voltages. The resulting flow of electrical current produces magnetic fields, which can then be recorded using sensitive magnetic sensors. More than 300 specialized sensors in the MEG helmet measure the magnetic fields generated by rapid changes of electrical activity in patients' brain cells. The MEG scanner's sophisticated instrumentation makes it possible to pick up the activity of neurons and to determine where in the brain this activity originates.

A MEG scan is noninvasive and painless. With no injections, radioactivity or strong magnetic fields, MEG is safe for children and adults. Unlike with some imaging tests, the machinery is quiet and almost never produces a feeling of claustrophobia. During MEG testing, brain activity in both wakefulness and sleep is ordinarily recorded.

Measuring by the Millisecond

Diagnostic methods for imaging the brain generally divide between two categories: anatomic and functional. CT and MRI are most common for anatomic imaging, while PET and fMRI are examples of functional imaging. Like EEG, MEG records the electrophysiological effect of neuronal activity over time; however, with its higher sensor count and simpler modeling physics, MEG has a higher source resolution. Additionally, recordings with MEG are reference-free; its signals are not attenuated by bone; and multichannel, whole-head, high spatial-density recordings are easily obtained.

By its very nature, MEG shows areas of function: It localizes the signals generated by neurons as they are activated, as they communicate and as activity spreads through them. MEG is sometimes called a functional imaging test, but it differs in significant ways from other such tests:

• The functional tests available at most centers are indirect measurements, dependent on changes in oxygen consumption (fMRI), glucose uptake (PET) and blood flow (SPECT). Conversely, MEG measures neuronal activity directly.

• While PET and fMRI measure changes in metabolism and blood flow, respectively, over many seconds, MEG measures electrical activity millisecond by millisecond. Localizing the entire sequence of activation as it evolves over time is what MEG does superbly. Hence, the activity of the whole chorus of neurons required for everyday actions (pressing on the accelerator) or abnormal episodes (an epileptic aura) — not just the maximally involved area — can be mapped in space chronologically as it changes. Like PET and fMRI, MEG "lights up" brain areas activated by a task.

In epilepsy, MEG can show the propagation of activity from one brain region over a few milliseconds or during the onset of a seizure; in fact, ictal MEGs constitute approximately 15 percent of MEG scans performed at Cleveland Clinic Epilepsy Center. MEG results are coregistered with anatomic images from MRI and are reconstructed three-dimensionally to show the exact areas of activity.

A Versatile Tool

The primary and best-established clinical applications of MEG are for:

• **Accurate mapping of functional areas** in the brain. This use can help surgeons contemplating the resection of a lesion to avoid eloquent areas of the brain responsible for important sensory, motor or language functions.

• **Precise localization of the source** of epileptic seizures in some patients being considered for epilepsy surgery.

MEG BY THE NUMBERS

Since Cleveland Clinic introduced MEG in 2008, the technology has been used to perform more than 300 evaluations in children and adults. MEG's importance in evaluating epilepsy patients is documented in additional statistics from Cleveland Clinic's experience:

• Patients undergoing MEG testing have ranged in age from 8 months to the eighth decade, with 39 percent in the pediatric group.

• In about 7 percent of pediatric cases, parents accompany their child into the MEG testing room, an innovation developed at Cleveland Clinic to make the experience more comfortable.

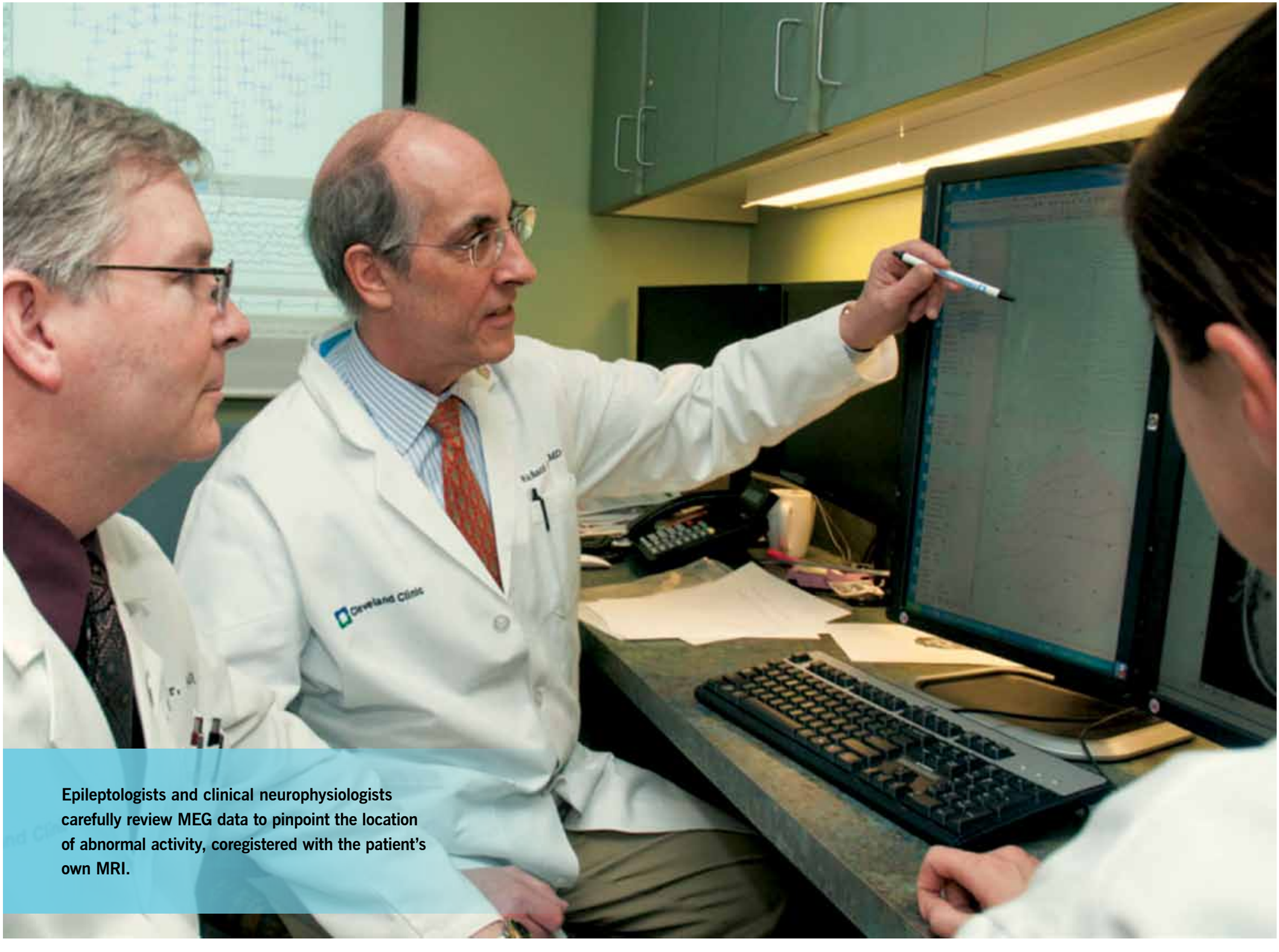
• Some 18 percent of MEG patients have implanted vagus nerve stimulators. The experience of the Cleveland Clinic Epilepsy Center MEG team, coupled with sophisticated noise reduction techniques, allows for recording of these patients, who often are denied MEG at other institutions due to the technical challenges with implanted electronic devices. We have also recorded MEG in patients with deep brain stimulators.

• Another 13 percent of MEG scans have been recorded despite other implants such as pacemakers, neurosurgical clips and stereo-electroencephalographic depth electrodes, or external devices such as law enforcement monitoring bracelets.

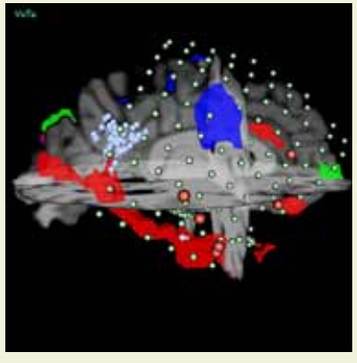
Parents are allowed to accompany their child into the MEG testing room, a practice that can calm and comfort pediatric patients.

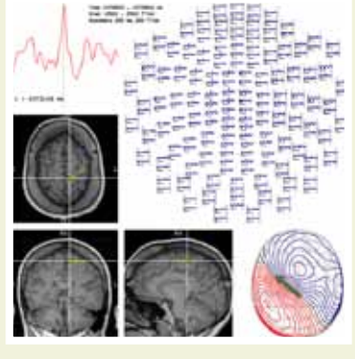
• Less than 1 percent of MEG recordings have been aborted for technical reasons.

• In approximately 30 percent of MEG recordings of epilepsy patients, the study shows no abnormality. In a crucial 40 percent, MEG results are deemed "essential or very helpful" to the epilepsy evaluation.



Epileptologists and clinical neurophysiologists carefully review MEG data to pinpoint the location of abnormal activity, coregistered with the patient's own MRI.





Above: Specialized display software, developed at the Epilepsy Center to fuse multimodal image information, shows the location of epileptic activity as determined by MEG, together with areas of normal function from fMRI, to determine placement of subdural grid electrodes (also shown) on a three-dimensional anatomical MRI.

Below: A MEG recording of an epileptic spike, along with source localization results on a patient's MRI.

ADVANCING KNOWLEDGE OF NEUROLOGICAL DISORDERS

A valuable resource for basic neuroscientists and behavioral biologists, MEG also benefits researchers in psychiatry, neurology, neurosurgery, language science and imaging who seek to understand how different areas of the brain respond, communicate and control action. At present, an NIH-funded study at Cleveland Clinic is employing MEG to assess patients with central pain and to plan their therapy with deep brain stimulation.

MEG is also helping to define "signatures" associated with neurological and psychiatric disorders, including Alzheimer's disease and depression. Other neurological disorders such as autism, currently diagnosed through behavioral observation, are being identified with MEG; eventually, MEG's electrophysiological markers may provide severity indication.

Ultimately, MEG can determine whether a patient with intractable epilepsy is a surgical candidate and, if necessary, MEG can guide electrode placement prior to surgical resection.

In epilepsy, MEG specifically may:

- **Identify focal epilepsy** in some patients with clinical diagnosis of generalized epilepsy. Sometimes, the EEG shows epileptiform activity that is widespread or otherwise impossible to clearly localize. MEG can pinpoint the origin of this activity and may, at times, identify a focal source for what had appeared to be generalized epilepsy.

- **Uncover and localize interictal spiking** in patients with no spikes on surface/scalp EEG. Occasionally, patients who clearly have seizures do not manifest interictal activity on their EEG, or the EEG activity is too vague to confidently identify as epileptic. MEG is far more sensitive to epileptic spikes and their origin.

- **Identify the spatial relationship** between a lesion and source of the epileptic activity. Sometimes, patients with lesions on structural imaging do not clearly show epileptic activity coming from the lesion area, or the rest of the workup is not consistent with the suspected location. In these situations, MEG can confirm that the epileptic activity is coming from the area of the lesion or that the patient has multiple areas of epileptogenicity.

- **Localize epileptic activity** in patients who have undergone surgery or suffered severe head trauma.

In patients who have failed epilepsy surgery, the EEG is especially difficult to interpret. Electrical signals detected by EEG electrodes attached to the scalp are distorted and smeared by the intervening layers of cerebrospinal fluid, skull and scalp. When the patient has a skull defect, either from craniotomy or traumatic injury, the EEG takes a circuitous course to the scalp, and results are misleading. Magnetic signals travel through these barriers with no distortion or attenuation. In these patients, MEG can precisely answer whether a recurrence of seizures arises from tissue adjacent to the original resection or from a different source.

- **Map function in the brain**. MEG can localize activity during defined sensory or cognitive tasks, thereby allowing for better presurgical mapping of eloquent brain areas to guide surgeons during procedures.

Ultimately, MEG can determine whether a patient with intractable epilepsy is a surgical candidate. If the patient must undergo intracranial recording with subdural or stereoelectroencephalographic (SEEG) electrodes preparatory to surgical resection, MEG can guide electrode placement to ensure coverage of all possible epileptogenic regions.

MEG at Cleveland Clinic: A Step Ahead

To localize the epileptic focus with more precision, Cleveland Clinic Epilepsy Center added MEG to its state-of-the-art diagnostic capabilities in 2008. We are one of a select number of institutions in the world with this technology, and Cleveland Clinic's system represents the newest generation of MEG scanners. Since its inception, the MEG laboratory has undergone continuous expansion as more physicians have found it an indispensable tool in patient evaluation.

Our MEG laboratory performs between 10 and 20 clinical scans per month, one of the highest clinical volumes in the world. Dedicated physician magnetoencephalographers with long track records in clinical neurophysiology and epileptology bring this intensive experience to bear on each patient's MEG scan.

Because they are complementary technologies, we obtain optimal data during testing by recording EEG and MEG simultaneously. The Elekta Neuromag® system at Cleveland Clinic records both MEG and up to 128 channels of EEG. Patients can be evaluated in a seated or supine position.

In the normal diagnostic process, MEG data go through a sophisticated series of steps:

- First, the data are processed by computer to remove interference caused by the environment, patient movement and other noncerebral sources of "noise"; this step takes many hours.
- Subsequently, several clinicians review the data to complete the localization process.
- Ordinarily, a report is sent to the requesting physician's office within two weeks.

There are occasional calls for emergency, or "stat," MEGs, which must be processed and interpreted within hours so that appropriate interventions can be made.

The range of Cleveland Clinic patients spans all ages and types of epilepsy. Our MEG scanner is calibrated for use not only with normal heads, but also in patients with abnormal brain structure, such as malformations of cortical development or traumatic brain injury.

Above: Sequential analysis of magnetic field activity allows investigation of the propagation of epileptic activity.

Below: During acquisition, technologists are in constant contact with the patient, monitoring video/audio along with signal quality.

CUSTOMIZING MEG AT CLEVELAND CLINIC

Cleveland Clinic Neurological Institute has a large referral network and a professional staff consisting of more than 300 physicians. Because the volume and urgency of MEG scans is greater than at most institutions, our neurocomputing and clinical neurophysiology teams have added new capabilities to the basic MEG system, making it uniquely advanced. These developments, several of which are unavailable in any other MEG laboratory, include:

- **Specialized software** to post-process the recorded MEG waveforms to eliminate sources of interference that would otherwise obscure brain activity. The MEG laboratory was placed in the middle of the hospital, adjacent to operating rooms and recovery areas, to guarantee easy access from patient care areas. Special care is required to eliminate sources of magnetic inteference from nearby electrical equipment, patient gurneys and vehicle traffic.

- **Continuous, synchronized digital video and audio recording** that enables direct correlation of the patient's physical actions with MEG waveforms. This capability is especially critical for epilepsy patients who have frequent seizures.

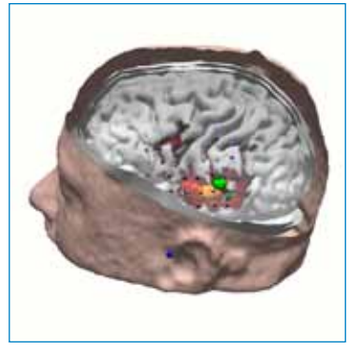
- **Online annotations** providing second-by-second testing and clinical information in the course of a MEG recording. The ability to mark segments of the recording during acquisition or review is crucial for efficient, accurate processing of data from epilepsy patients.

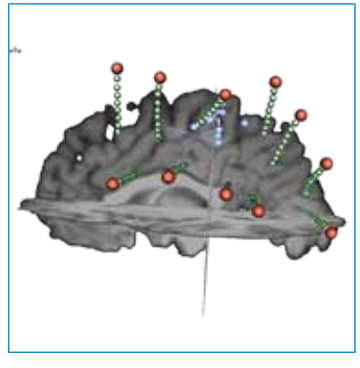
- **Live graphical display** of patient position within the MEG array. The exact position of the patient within the sensing helmet is continuously measured, and a pictorial display of the patient's head inside the array enables the technologist to tell at a glance whether the patient must be repositioned.

- **Advanced stimulators** permitting better evaluation of sensory responses. Stock factory stimulators have been replaced with a sophisticated multichannel stimulator of the type used in the Epilepsy Monitoring Unit and operating rooms, allowing parallel stimulation of multiple anatomic sites and simultaneous MEG and EEG recording of the brain response.

- **An online database** where raw results and interpretations are housed to facilitate ongoing quality assessment. Included are merging of live and retrospective markers/annotations, generation of reports automatically exported to the electronic medical record and automatic backup.

- **Total integration** of simultaneous EEG. MEG and up to 128 EEG channels of scalp or specialized electrodes are always recorded together. Customized jackbox and impedance measurement, directly compatible with commercial EEG systems, eliminates the patient wait time and error-prone translation from one jackbox to another at other sites.





Careful alignment and coregistration of multimodal information facilitates surgical planning.

Above: In this volume-reconstructed image of the brain, the source of epileptic activity is shown in green and its spread over the cortex is shown as red and orange intensities. This image includes the locations of subdural electrodes for direct comparison of the magnetic signal with the electrical activity.

Below: In this 3-D brain-slice display, the blue MEG sources are shown in anatomical relation to the green SEEG electrodes. Physicians can rotate, zoom or walk through brain slices in order to best illustrate the epileptogenic region.

A Unique View into the Brain

Staff at Cleveland Clinic Epilepsy Center and Cleveland Clinic Florida manages more than 4,000 adult and 2,000 pediatric patient visits a year, and intensively evaluates 400 to 500 patients annually for surgery. It is to these difficult-to-treat patients — in whom precise localization of the epileptic focus is the critical factor — that Cleveland Clinic devotes the majority of its MEG testing capability.

Referring physicians can take advantage of MEG technology to aid in the diagnosis and treatment of many conditions their patients face. MEG technology allows for the combination of structural and functional information, thus achieving both high spatial resolution and high temporal resolution — a combination that no other modality for studying the brain can offer.

Will he fit into the MEG sensor array? Mock-up of the measuring system helmet ensures a comfortable fit.

Referring Your Patient for MEG

To accommodate your patient's needs and expedite access, we can schedule a MEG within 24 to 48 hours of your referral. For more information or to make a referral to Cleveland Clinic Epilepsy Center, please call **216.445.0601** or toll free, **800.223.2273**, **ext. 50601**.

Visit us online at **clevelandclinic.org/epilepsy**.

Whether you are referring from near or far, our complimentary eCleveland Clinic service, Dr**Connect**, offers secure access to your patient's treatment progress at Cleveland Clinic. To establish a Dr**Connec**t account, visit **clevelandclinic.org/drconnect** or email **drconnect@ccf.org**.