Magnetoencephalography (MEG)

INTRODUCTION

Magnetoencephalography (MEG), also known as Magnetic Source Imaging (MSI) is the noninvasive measurement of the magnetic fields generated by brain activity. Typical MEG recordings are made within a magnetically shielded room using a device that has 100 to 300 magnetometers or gradiometers (sensors). They are arranged in a helmet-shaped container called a Dewar. The Dewar is filled with liquid helium needed to produce superconductivity. The brain sources producing the magnetic field maps can be easily mapped and displayed on a co-registered MRI. This results in a visual display of normal brain activity such as the location of eloquent cortex for vision, touch, movement, or language. It displays equally well abnormal brain activity such as epileptic discharges. Such depictions are useful in pre-surgical brain mapping in patients with epilepsy, brain tumors, and vascular malformations.

Importance of epilepsy surgery. Recurrent seizures, resistant to pharmacotherapy, are associated with decreased survival and increased mortality ratios. Patients who experience freedom from seizures have lower mortality rates when compared with those who continue to experience seizures.[1] Early resective epilepsy surgery has beneficial effects on progressive and disabling consequences of uncontrolled seizures. Timely recognition and referral are vital to realization of the benefits of epilepsy resective surgery.[2,3]

Value of MEG in localization and resective surgery. A cardinal principle in resective surgery is to remove only the abnormal tissue and preserve normal functional tissue. This is particularly crucial in the cortical regions of the brain. Normal and abnormal tissues are often in close proximity and may appear contiguous and indistinguishable to naked eye inspection.

Even when the abnormal structure, such as a vascular malformation, may be obvious, the location of a normal eloquent brain tissue cannot be determined without specialized testing. Eloquent areas are those subserving essential functions such as the sense of touch, vision or language. They often surround a lesion that requires extirpation. The value of MEG and certain other tests lies in their ability to localize and demarcate both normal and abnormal functioning regions of the brain.

SUMMARY OF AVAILABLE LOCALIZATION TECHNIQUES

MEG is one of several neurophysiological tests used to localize brain function. Unlike MRI—which measures static structures—neurophysiological tests such as MEG, PET, SPECT, EEG, and the Wada test measure various aspects of brain metabolism or function. Functional MRI (fMRI) measures the average changes in oxygenation of cerebral blood flow over approximately one minute between a task and a rest period.

- **EEG**, like MEG, measures brain activity with millisecond resolution. Both MEG Model Policy are far more sensitive than PET and SPECT to rapid changes in brain activity. Such rapid changes occur during the propagation of a seizure. EEG can be recorded noninvasively like MEG but surface EEG has limited resolution: it usually has inadequate sensitivity for presurgical decisions.
- **Intracranial EEG** (ICEEG) has the millisecond resolution and localization sensitivity of MEG but requires a major neurosurgical procedure to implant electrodes on the surface or in the depths of the brain. These procedures carry potential risks and expense of intensive care unit hospitalization. In addition, implanted electrodes can only detect brain activity occurring within a few millimeters from the electrodes requiring some a priori knowledge of the source of the signal being investigated and/or a large exposure of the brain for implantation of up to 150 electrodes at a time. Most intracranial EEG (or "electrocorticography" or "ECoG" or depth electrodes) is usually performed in restricted regions on one hemisphere at a time because of the surgical risks of bilateral implantations, or in a few lobes, because of the risk of hemorrhage.
- **MRI**, unlike the following functional tests, provides a structural estimate of the location of scar tissue or malformations of cortical development, which are major causes of intractable epileptic seizures.
- **fMRI** provides an indirect estimate of the location of active brain tissue by measuring the changes in venous blood oxygen levels produced by neuronal activity.
- **PET** images reveal relative uptake of radioactively labeled glucose or neurotransmitters. They show areas of the brain with increased or decreased metabolism or neurotransmitter binding on a time scale of several minutes.
- **SPECT** scans are images of cerebral blood flow averaged over the course of one to two minutes made by

Approved by the AAN Board of Directors in May 2009

measuring the radioactively labeled tracer material as it travels though the blood vessels.

- **Neuropsychometric testing** is performed prior to the Wada test. It assesses virtually all brain functions but usually does not localize functions.
- **The Wada test**, also known as the intracarotid amobarbital anesthesia test, is an angiographic technique where one hemisphere of the brain is given a short acting barbiturate, amobarbital, putting half the brain "asleep" for about five minutes and permitting an estimation of language and memory functional capacity of the unaffected hemisphere. In the typical Wada test, after a washout period of half an hour, the angiographic catheter is repositioned to the other carotid artery and the test is performed a second time in the contralateral hemisphere to provide an estimate of language and memory functional capacity in each hemisphere.

All of the above functional tests are useful in the evaluation of patients prior to surgery for intractable epilepsy, but none of these techniques has been rigorously and prospectively tested by evidence-based methodology for their respective indications. With rare exceptions health coverage policies recognize all of the above technologies as valid covered procedures.

COMPARISON OF INTRAOPERATIVE TECHNIQUES

In the operating room, direct brain recordings of spontaneous EEG activity, known as "electrocorticography" or "ECoG" or "evoked response testing" (also known as evoked potentials), can be used to identify normal and abnormal brain tissue. Direct recordings like this are time-intensive and may extend the duration of anesthesia.

Surface EEG and surface evoked potential recordings currently lack the anatomic precision to be helpful for pre-surgical mapping. Functional MRI (fMRI) is of limited value because many lesions, especially vascular lesions including some tumors, have altered hemodynamics and do not produce results that are reliable enough on which to base surgical decisions. Magnetic evoked response testing has been directly compared to electrocorticography and has been shown to produce equivalent localization of eloquent cortex with a noninvasive technique that can be performed days to weeks prior to planned surgery allowing the surgical planning to be determined well in advance of surgery.

CRITICAL EVALUATION OF MEG AS A DIAGNOSTIC TECHNOLOGY

MEG is a newer technology when compared to MRI, PET, SPECT, ICEEG and the Wada test. For presurgical localization and functional identification a few of the earlier tests have become the standard of practice, by default of chronologic precedence. Not all of them have undergone rigorous comparative critical appraisals.

ICEEG, for instance, is often used as the reference (gold) standard for localizing an epileptic focus in presurgical evaluation of epilepsy patients.[4,5] This invasive test method, not without morbidity, may occasionally yield incorrect findings or may even not detect a focus.[6] Therefore, in some centers, a prior MEG recording has guided an ICEEG, thus avoiding incorrect invasive electrode placements.

The Wada test has also been successful since 1949 for language and memory localization. It has both merits and shortcomings when compared with newer tests.[7] It is invasive, uncomfortable and carries certain morbidity. fMRI, neurobehavioral testing, PET-SPECT scans, MEG and transcranial magnetic stimulation are emerging as possible alternatives to the Wada test. Both the Wada and more recent techniques are now available for use depending on the diagnostic need and patient characteristics.

The above are two examples, from among several in diagnostic medicine, where existing reference standards may be less than ideal. Generally a diagnostic test, even if less than perfect, becomes the reference standard by virtue of its longevity. It is against this standard, although imperfect at times, that newer tests are measured. The concept of a flawed or incomplete reference standard is not an unfamiliar one. Therefore, it has received due attention from several authorities and policy makers. In the absence of perfection, some alternatives may serve, in lieu of a rigid gold standard, for making decisions. They are: results of several tests, an "umpire" test, natural history of the disease process, clinical follow-up and prognosis after treatment.[8-10] Until uncertainties clear, newer diagnostic technologies deserve periodic evaluations rather than outright acceptance or rejection. With this as a background, it is reasonable to find out if MEG could inform surgical decisions without duplicating data from other tests.

MEG AS A SOURCE OF NON-DUPLICATIVE (NON-REDUNDANT) OR SUPPLEMENTAL INFORMATION

In resections for epilepsy:

The MEG has been scrutinized more frequently than many of the earlier technologies; and these evidence based efforts are now unfolding to reveal the utility of MEG. The value of MEG lies in its ability to provide either new and non-duplicative or supplemental information to existing localizing technologies. The following studies provide supportive details.

Two recent prospective studies meticulously documented the unique contributions of MEG to evaluation of patients undergoing epilepsy surgery.

Sutherling et al. evaluated MEG's potential for making surgical decisions in neocortical epilepsy.[11] They used a standard comprehensive presurgical epilepsy workup including MEG and all the above functional measures. Their blinded prospective study found that:

- MSI influenced ICEEG planning in one-third of all patients. It provided non-redundant information in 33% of 69 presurgical patients.
- MSI changed the overall surgical decisions in some instances by altering planned bilateral resections to less risky unilateral resections.

Knowlton et al. studied 77 patients who had completed ICEEG.[12,13] Using ICEEG as a reference, they had derived sensitivity, specificity and predictive values for MSI, 18FDG-PET and SPECT. Their results show that:

- MSI performed better than PET and SPECT in each of the metrics gathered.
- For those with positive MEG information, the sensitivity for a seizure-free (Engel Class I) outcome was 72% and the specificity was 70%, the positive predictive value was 78%, and the negative predictive value was 64%.
- MEGs showing multifocal or generalized epileptic discharges early in the surgical evaluation process had a high negative predictive value for poor outcome. This finding was sufficient to stop further work up.

A desirable result of MEG recordings would be to increase the accuracy for intracranial EEG placement. Among Knowlton's 77 patients, 18 had their initial intracranial EEG placement plans modified with resulting better localization of the focus.

The work of Sutherling[11] and Knowlton[12,13] have demonstrated the value of MEG using prospective data collection. Earlier retrospective analyses also had revealed markedly parallel results. Paulini found that in 25 of 105 patients neither interictal nor ictal EEG detected a seizure localizing focus.[14] The MEG, however, localized the seizure origin to a single lobe. Six of the 11 had a seizure free surgical outcome, and the remaining 5 experienced a >50% frequency reduction.

Wheless et al. found that ictal intracranial video EEG was the only method that exceeded MEG's potential in predicting the epileptogenic zone.[15] They raised the possibility that MEG may obviate the need for invasive EEG in some cases. Assaf et al. performed simultaneous interictal EEG and MEG in 26 temporal lobe epilepsy patients.[16] Their source analysis showed distinct and useful localizing information which could predict surgical outcomes.

In resections for non-epilepsy lesions:

MEG provides pre-surgical guidance in patients with resectable lesions. Grover et al. recorded visually evoked cortical magnetic field in 21 patients who underwent surgery for parieto-occipital tumors.[17] Displaced or abnormal responses were seen in 15 patients with disruption of pathway in one patient. Three of 21 patients had alterations in the surgical approach or the planned resection based on the MEG findings.

Korvenoja compared functional MR (fMR) images and MEG to localize the primary sensory-motor cortex in 15 patients with a lesion near the same cortical areas.[18] The intent was to minimize damage to normally functioning regions of these cortices during surgery. This prospective study showed that MEG enabled a more reliable localization of sensory motor cortex compared with fMRI.

Language and memory functions may reside in both or one hemisphere in patients with epilepsy. Determination of laterality is crucial in resective surgery that aims to preserve as much language and memory functions as feasible. Towards this end, the intracarotid amobarbital test (Wada test) has long been as the standard bearer. There are drawbacks to the Wada test – the procedure is quite invasive, uncomfortable to the patient and it carries morbidity. Several alternatives such as neuropsychological testing, fMRI, MEG, behavioral testing and SPECT-PET are available. Each has certain merits and disadvantages. Pelletier compared all the Wada alternatives in a comprehensive review. MEG, while requiring patient cooperation, had the advantage of being a non-invasive direct measure with excellent temporal resolution.[7]

INDICATIONS

Epilepsy – Pre-surgical evaluation in patients with intractable focal epilepsy to identify and localize area(s) of epileptiform activity. MEG can be valuable when discordance or continuing questions arise from amongst other techniques designed to localize a focus.

Tumors and AVM Surgeries – Pre-surgical evaluation of brain tumors and vascular malformations. The aim is to identify, localize and preserve eloquent cortex during resective surgery.

LIMITATIONS

- MEG cannot replace, but may guide the placement of intracranial EEG and, in some patients, avoid an unnecessary intracranial EEG.
- MEG is not the first order of test after clinical and routine EEG diagnosis of epilepsy. It is one of several advanced pre-surgical investigative technologies. The need for MEG is much lower than surface EEG and anatomical imaging studies.
- MEG is not a stand-alone test. To realize its optimum clinical potential a comprehensive team evaluation, such as that available in comprehensive epilepsy centers, is necessary. The team usually comprises a neurologist with expertise in epilepsy, a neurosurgeon, MEG-physicists, psychologists, nurses and staff experienced in treatment of seizure disorders.

CODING FOR MEG

Procedure Codes:

95965	Magnetoencephalography (Meg), Recording and Analysis; for Spontaneous Brain Magnetic Activity (Eg, Epileptic Cerebral Cortex Localization)
95966	Magnetoencephalography (Meg), Recording and Analysis; for Evoked Magnetic Fields, Single Modality (Eg, Sensory, Motor, Language, or Visual Cortex Localization)
95967	Magnetoencephalography (Meg), Recording and Analysis; for Evoked Magnetic Fields, Each Additional Modality (Eg, Sensory, Motor, Language, or Visual Cortex Localization) (List Separately in Addition to Code for Primary Procedure)

ICD-9 CODES THAT SUPPORT MEDICAL NECESSITY:

All ICD-9-CM codes listed below may be viewed as medically necessary. This listing may not represent an all inclusive list of submissible ICD-9-CM codes. There may be other diagnostic codes that are deserving of consideration for coverage. Such instances may require individual consideration.

191.1	Malignant Neoplasm of Frontal Lobe
191.2	Malignant Neoplasm of Temporal Lobe 1
91.3	Malignant Neoplasm of Parietal Lobe
191.4	Malignant Neoplasm of Occipital Lobe
225.0	Benign Neoplasm of Brain
345.41	Localization-Related (Focal) (Partial) Epilepsy and Epileptic Syndromes with Complex Partial Seizures, with Intractable Epilepsy
345.51	Localization-Related (Focal) (Partial) Epilepsy and Epileptic Syndromes with Simple Partial Seizures, with Intractable Epilepsy
747.81	Congenital Anomalies of Cerebrovascular System

ICD-9 CODES THAT DO NOT SUPPORT MEDICAL NECESSITY

Use of any ICD-9-CM code not listed in the "ICD-9-CM Codes that Support Medical Necessity" section of this LCD will be denied. In addition, the following ICD-9 CM codes are specifically listed as not supporting medical necessity for emphasis, and to avoid any provider errors.

780.02 TRANSIENT ALTERATION OF AWARENESS

SOURCES OF INFORMATION AND BASIS FOR DECISION

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