

Over the years, the *Journal of Clinical Neurophysiology* and its parent, the American Clinical Neurophysiology Society, have collaborated with other related societies in championing the development of new technologies and in promulgating their appropriate clinical use. As such, in 2009, the Journal published a position paper from the American Clinical Magnetoencephalography Society on the value of magnetoencephalography in the evaluation of focal epilepsies (Bagic et al., 2009). Continuing in this tradition and as a follow-up to the aforementioned position statement, the Journal is now publishing a series of guidelines for magnetoencephalography that were written by the American Clinical Magnetoencephalography Society Clinical Practice Guidelines Committee. The background for and intent of these guidelines are discussed in detail in the following guest editorial. It should be noted that the American Clinical Neurophysiology Society Council has reviewed and endorsed these guidelines.

John S. Ebersole,
Editor-in-Chief

REFERENCE

- Bagic A, Funke ME, Ebersole J. ACMEGS Position Statement Committee. American Clinical MEG Society (ACMEGS) position statement: the value of magnetoencephalography (MEG)/magnetic source imaging (MSI) in noninvasive presurgical evaluation of patients with medically intractable localization-related epilepsy. *J Clin Neurophysiol* 2009;26:290–293.

Turning a New Page in Clinical Magnetoencephalography: Practicing According to the First Clinical Practice Guidelines

BACKGROUND AND PRIOR ART

Magnetoencephalography (MEG) has been in existence for four decades (Cohen, 1968, 1972), and now, a large body of literature exists (Bagić et al., 2009), including well-designed studies demonstrating its clinical value (Knowlton et al., 2008a, 2008b, 2009; Sutherling et al., 2008). Clearly, MEG is no longer a “new technology,” and it is a propitious time to promulgate guidelines for MEG evaluations and to practice according to them. The main reasons, of course, are the usual ones: a crying need to ensure that MEG laboratories are adhering to good practice, a desire for systematic comparison across laboratories and in multicenter studies that demand consistent practices, and some minimal standards that both laboratory directors and payers can point to. It also is in keeping with the tradition of the American Clinical Neurophysiology Society, which for the past several decades has formulated and revised Clinical Practice Guidelines (CPGs) on a variety of neurophysiologic diagnostic tests (see <http://www.acns.org/guidelines.cfm> for a listing).

Other bodies will dictate what good practice is if we do not. Society and regulatory bodies want to ensure competency, and medical practitioners expect leadership toward quality (Clavien et al., 2005; Nahrwold, 2010). With health care reform high on the list of federal priorities and no money to spend on it, there will certainly be added scrutiny focused on new and expensive procedures. The very existence of voluntarily produced and expertly reviewed guidelines demonstrates a level of professionalism and maturity that establishes a baseline of clinical credibility.

Clinical Practice Guidelines have been a reality in the medical profession for decades (e.g., Schorow and Carpenter, 1971; Talley et al., 1990; Wiebe, 2010; <http://www.acns.org/guidelines.cfm>). Yet, actual penetration of these guidelines into clinical practice varies (Haneef et al., 2010; Wiebe, 2010). To move toward excellence in MEG, as in all areas of clinical medicine, we must first obtain a clear picture of the current practices and the roles of the people practicing. Hence, the process of establishing the American Clinical Magnetoencephalography Society’s (ACMEGS) first CPGs started with an assessment of the state of clinical MEG in the United States (Bagić, 2011). This survey was conducted in 2008 and included 90% of MEG centers providing clinical services at that time. Of course, not all individuals practicing clinical MEG from each participating center responded, and the field has dramatically grown even further in the past three years. Despite these and other limitations, this survey is the first systematic attempt to recount the prevailing clinical MEG practice in the United States, and it provides several important points to consider (Bagić, 2011).

The survey revealed a diversity of organizational structures and a large variability in daily practice. In more than a quarter of the surveyed centers, clinical reports of epilepsy MEG studies are signed by nonneurologists, two of whom were nonphysicians. Another remarkable finding was that the turnaround time from test to report ranged from 0.5 to 30 days, and this reporting time variability was not related to volume. These results demonstrate not only numerical variability but also suggest fundamental differences in practice and raise important questions. Should those of us struggling to complete our analysis and reports within even several days or a week be embarrassed that we cannot complete them within a day? Should we attempt to massively streamline our practice? And on the flip side, is there any reason why reports should take up to 30 days to send out in any clinical MEG center?

Integration into the overall clinical neurophysiology community is crucially important. Considering the complementary nature of MEG and EEG techniques (Barkley and Baumgartner, 2003, Ebersole and Ebersole 2010), it was reassuring to find that all centers claimed to be using EEG collected simultaneously with MEG in some way, but it remains concerning that EEG is used variably in study processing and interpretation. Some centers use EEG only to define the time slice of the MEG signal for dipole modeling, while rare centers also engage in EEG source localization. Although only a small point, the fact that the number of averaged responses used for mapping a particular modality ranged across centers by a factor of 19 is further illustrative of a wide variability in practice—or is a high number of averages an indication of fundamentally low signal quality?

Does an expertise in EEG, with its accompanying understanding of clinical neurophysiology, convey an automatic readiness to interpret MEGs, or is it irrelevant? Both of these opposing positions were endorsed by some survey participants. Nevertheless, it is clear to the more experienced clinical magnetoencephalographers that having an MD/DO and/or PhD degree, having pursued a residency in neurology, neurosurgery, or radiology, or even an Accreditation Council for Graduate Medical Education-approved fellowship is insufficient per se. Respondents were more declaratively united on the need for some kind of standardized training and an assurance of a certain amount of “experience” in analyzing and interpreting MEGs, than on the specifics. Most medical professionals would agree that five years in the field (after training) represents a significant experience (McCray et al., 2008). However, in this survey, “experience” was purely chronologically based and varied widely, depending on the institution, with some busy magnetoencephalographers reading more clinical MEGs in an average month than some in the less busy laboratories see in five years (Bagić, 2011).

The survey demonstrated that both physicians and nonphysicians recognize the need for clinical MEG standards. Generally, 81% of the surveyed participants displayed a positive attitude by welcoming an “appropriate form of standardized training WITH certification” or believing that it “would improve the quality of patient care and help propel clinical MEG.” One eighth of the respondents thought that clinical MEG standards already existed, and some even believed that “everybody in the field knows the standards.” Yet either way, one out of five respondents still believed that “standards would not change what they do” (Bagić, 2011). It has been suggested that practitioners are far more likely to change their behavior if there is direct interaction between the subject matter experts and the practitioners (Akbari et al., 2008). For clinical MEG, still very much a growing field, this presents a great opportunity.

So, the process of defining the first CPGs for MEG began. There are some initial philosophical questions that our group attempted to grapple with to create some context for our guidelines. These questions, and some brief summaries of our answers, are included below.

PHILOSOPHICAL QUESTIONS

1. *Who is the target audience? Current practitioners of the MEG art? Trainees and those who educate them? Administrators and department chairman at hospitals considering establishing an MEG laboratory (center)? Payers? Referring physicians?*

The guidelines are not meant to be a comprehensive how-to manual for MEG. They are aimed at those already trained in MEG who are responsible for ensuring that their laboratory is conducting high-quality studies that are considered the standard of practice. The guidelines are meant to answer the specific questions that ensure some level of uniformity across laboratories. Just as with any other clinical test, reporting style differs from one MEG center to another. Physicians referring patients to MEG laboratories have sometimes found that the reports they receive back are impenetrable or do not answer the clinical question for which the patient was sent to the laboratory. Hence, there is a need to ensure that the test results are understandable and meet their expectations.

2. *Are these guidelines meant to be “minimal standards” or “best practices”?*

The ACMEGS was formed, in part, to advocate for best practices in MEG so that high-quality clinical answers are delivered, and hence, MEG testing becomes even more valuable in clinical care. Therefore, even though the guidelines are not meant to establish a legal “standard of care,” they are designed to point us in the direction of excellent standards of practice—not just minimal requirements. Not all laboratories are equipped the same, either in terms of their instrumentation or their operation, naturally, so not all laboratories can be expected to do things exactly the same way. We should assume that these initial guidelines are living documents that, with more maturity in the field, will eventually evolve into “best practices.”

3. *How detailed should the guidelines be?*

Guidelines developed at this stage of MEG must navigate a fine line between being so restrictive as to stifle innovations and improvements versus being so vague that they are simply impractical platitudes. However, there is no point in establishing guidelines that are too broad lest they leave new users with no guidance at all. While there are many laboratories that are quite comfortable and confident with their work product, others, especially those just starting up, are hungry for some relatively specific starting points. Hence, the level of detail included in these guidelines was meant to offer the minimal practical guidance desired by the MEG community. The specifically recommended settings may not cover every single clinical circumstance encountered, but they are meant to serve as excellent starting points, which have been verified in practice.

4. Shall we include only Center for Medical Services-approved clinical studies, or provide more general guidance that can be extrapolated to the conduct of research studies?

These guidelines concentrate on the essential elements but do not dictate which services should be provided. Educational and research endeavors, by ACMEGS as well as by other organizations and universities, will provide the foundation for extending MEG studies into many realms of investigation. However, the guidelines focus on established areas where it is known that MEG works well. Magnetoencephalography's strength, and the primary reason for referral of patients to the MEG laboratory, is in *localization*. It is on the capability for localization that the guidelines focus, rather than on typical normal/abnormal decisions that depend on a normative database (as in traditional evoked potential studies). Although there are some promising applications for MEG that may someday become commonplace in clinical practice, these guidelines are meant to focus on the two established indications for MEG: localization of epileptic foci and presurgical functional brain mapping in patients with operable lesions.

5. What are the assumed technical standards for the equipment that we expect to be employed in this application? Do we need to specify, or leave to others?

Because of the relatively high cost and comparative adolescence of magnetoencephalograph manufacturing, MEG recording systems are not commodities, and MEG analysis packages are not uniform. We chose to restrict ourselves to whole-head systems because these certainly are the standard for clinical use, but we expect that more advanced specifications, such as acceptable noise performance or adequate analog-to-digital converter resolution, will continue to evolve. Given the enormous capital costs of MEG apparatus, it is not reasonable to expect replacement or upgrade frequently.

INTENT AND PRACTICAL APPLICATION OF THE GUIDELINES

The main thrust of the CPGs development effort was to provide guidance that will help to improve the consistency and quality of the clinical application of MEG. The CPGs included in this journal are purposely not called "standards" but rather "guidelines." Guidelines are just that: they are meant to be helpful not dictatorial; they are meant as a starting point not a full prescription. Because these Guidelines are essentially a consensus starting point, there will be many laboratories, especially the better established ones, doing things slightly differently. The important thing is for laboratories to be *aware* that there are guidelines and to use them to make sure that they are at least living up to the basics of the Guidelines. It is by pushing the envelope outside of established practice that modern medicine innovates, either to improve accuracy and quality or to improve efficiency and cost. The Guidelines will probably be of most help to laboratories that do not know exactly what to do for each type of test and want to start from a known place.

It is not surprising in the translation of a basic research technology into a clinical diagnostic technique that the backgrounds and career orientations of those involved in MEG to date have been quite inhomogeneous. In this regard, the field of MEG today is quite similar to where the field of EEG was in the 1950s, because EEG and evoked potentials emerged from research laboratories into clinical practice. At that time, many of the world's experts were research scientists without medical training, as exemplified by the career of Peter Kellaway, PhD, to cite just one example (Mizrahi and Pedley, 2004). The Guidelines recognize these differences and are meant to help pull the MEG community together for clinical purposes. Clinical Practice Guideline 4 (Bagić et al., 2011) deserves special mention because some may view it as an attempt at de facto credentialing. While it is possible that credentialing of personnel and accreditation of laboratories will be considered in the future, the field is young and the contributions of a variety of neuroscientists are critical to continued nurturing of the field. It is anticipated that laboratories will reexamine their procedures as a result of these guidelines, but it is not expected that any individuals currently involved in the acquisition or processing of magnetoencephalograms will suddenly be excluded from these activities. On the contrary, this document points up the scarcity of good training programs in MEG and may help to bring together the ideas for a body of knowledge that should be part of the curricula in some fellowships or included in certain examinations. Clinical Practice Guideline 4 was built around the concept that these CPGs establish (1) best practices in 2011 where possible, (2) a need for and challenge to the MEG community to get training in place, and (3) a recognition of the important role of nonphysician MEG scientists and excellent technologists. Should there come a time when certification and/or laboratory accreditation is considered, there will doubtless be a period of grandfathering and other transitional measures required. At that time, an appropriate degree of sensitivity should be demonstrated toward experienced practitioners and their diverse routes to clinical practice, according to well-established approaches that have already been applied in other medical specialties.

There is no intent within these documents to disenfranchise anyone. Rather, they should encourage all of us to advance to the next level. They are intended for everyone in the field and those who intend to come into it. They clearly raise the bar for all of us, that is, they represent—purposely—a considerable challenge for each and every member of the community. Judicious implementation of the CPGs should be supplemented with and facilitated by structured comprehensive educational activity covering MEG from basic science to best practices. These CPGs provide a set of practical recommendations that should help laboratories and clinicians to practice clinical MEG more uniformly and consistently, with all the direct and fringe benefits of such a new reality.

RESULTS OF A TEAM EFFORT

After more than two years of work, the ACMEGS 10-member CPG Committee defined four final documents: CPG 1: Recording and Analysis of Spontaneous Cerebral Activity (Bagić, Knowlton, Rose and Ebersole, 2011a); CPG 2: Presurgical Functional Brain Mapping Using MEG Evoked Fields (Burgess, Funke, Bowyer, Lewine, Kirsch and Bagić, 2011); CPG 3: MEG–EEG Reporting (Bagić, Knowlton, Rose and Ebersole, 2011b); and CPG 4: Qualifications of MEG–EEG Personnel (Bagić, Barkley, Rose and Ebersole, 2011). Each of these documents was authored by specific task forces (subcommittees), with the role of each member as indicated on the respective document. All final versions were approved unanimously by the ACMEGS Board, and we are particularly pleased that they were also endorsed by the American Clinical Neurophysiology Society Council.

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American Clinical Magnetoencephalography Society Clinical Practice Guideline 1: Recording and Analysis of Spontaneous Cerebral Activity*

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(*J Clin Neurophysiol* 2011;28: 348–354)

The following are considered “minimum standards” for the routine clinical recording and analysis of spontaneous magnetoencephalography (MEG) and EEG in all age-groups.

Practicing at minimum standards should not be the goal of an MEG center but rather a starting level for continued improvement. Minimum standards meet only the most basic responsibilities of the patient and the referring physician.

These minimum standards have been put forth to improve standardization of procedures and to facilitate interchange of recordings and reports among laboratories (centers) in the United States. Epilepsy is currently the only approved clinical indication for recordings of spontaneous cerebral activity.

LABORATORY (CENTER) ENVIRONMENT

General Layout of the Center

Magnetoencephalography center should be designed and equipped to meet the safety requirements of the state Department of Health for neurodiagnostic laboratories, while meeting all functional requirements necessary to obtain MEG–EEG recordings that meet at least minimum standards.

Magnetically Shielded Room

Magnetically shielded room that conforms to the current operational and safety standards should be used. The entire magnetically shielded room, including adjustable lighting system and audio–visual communication system, has to be inspected regularly to ensure proper operation.

Patient Bed and/or Chair

Patient bed and/or chair must be nonmagnetic and appropriate for use with the MEG system. Both must meet appropriate safety standards, including ensuring patient safety in the case of an epileptic seizure, drug reaction, or other potentially dangerous event. These may include a safety belt, protective rails, or other appropriate means.

Procedure Preparation Room

Procedure preparation room should be designed and equipped according to the regulations of the state Department of Health to optimize patient setup. Such a room is recommended for protecting patient’s privacy, providing explanations and instructions, changing and storing patient clothing, placing and removing EEG electrodes, and the like. This room would particularly facilitate patient flow when several studies are performed daily.

Measurement System

A Food and Drug Administration–approved whole head system is necessary to record simultaneously from the entire cerebrum. All components of the MEG system, both hardware and software, must be Food and Drug Administration approved.

Simultaneous recording of MEG and EEG is most beneficial for a clinical epilepsy study. (refer General Recommendations for Analysis of Spontaneous MEG–EEG Recordings for more details). Thus, if an EEG module is not integrated within a whole head system, standard EEG equipment meeting existing Food and Drug Administration regulations and American Clinical Neurophysiology Society guidelines should be used. Technical standards recommended by the American Clinical Neurophysiology Society and the International Federation of Clinical Neurophysiology should form the basis for the selection of clinical EEG equipment.

Head Position and Digitization

Because exact information about the relative position of the head with respect to the sensor array is necessary for source localization, a reliable digitization system must be used to locate the head position. Most often, this is accomplished by determining the position of several “head position indicator” coils while the patient is in the array. Transient electrical signals within the head position indicator coils on the head create magnetic sources that can be localized by MEG, thus providing the position of the head in sensor space. Before recording, the positions of at least three external fiducial points (usually nasion, left preauricular point, and right preauricular point), head position indicator coils, and/or other anatomic landmarks for creating the Cartesian coordinate that allows coregistration of MEG data with MRI for source localization.

*Revisions of the document authored by the task force were made and the final version was approved unanimously by the ACMEGS Board (Anto I. Bagić, Gregory L. Barkley, Richard C. Burgess, Michael E. Funke, Robert C. Knowlton, Jeffrey D. Lewine) on December 18, 2010.

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Head position measurement is recommended before and after each recording segment (block), or continuously where available, to quantify any head movement and to determine the quality of the data recorded in the segment.

In preparation for an MEG-EEG study, a standardized digitization procedure commensurate with the MEG system must be followed to ensure accurate head localization in the sensor space, continuous head position tracking where available, and accurate coregistration of MEG data with subject's MRI for source localization.

Sampling Frequency

Sampling frequency of the MEG system must be set appropriately to ensure adequate acquisition of the signals of interest. The frequency of a low-pass filter of one half or less of the sampling frequency should be applied to the data before digital conversion to avoid aliasing. A high-pass filter is usually required to minimize effects of large low-frequency signals, but unlike EEG, spontaneous MEG recordings can be performed without a high-pass filter ("direct current coupled").

Real-Time Monitoring of Data Quality

The ongoing waveforms of a sampling of MEG and EEG channels should be displayed in real time to monitor the quality of the recording. Displays of electrooculogram, ECG, and electromyogram may also be useful.

Temporal Synchronization of Data

All recorded data must include the same synchronized time signal irrespective of the applied method of synchronization.

Quality Control Routines

Appropriate sensor tuning and overall quality control procedures must be performed regularly according to operational instructions of the particular MEG and EEG systems. Confirmation of accurate system performance using a phantom should be performed as often as feasible, preferably weekly.

Acquisition of Anatomic Image

A volumetric scan with recognized high neuroanatomic fidelity (such as T1-weighted gradient echo or multiecho flash with two different flip angles) is required. Voxel dimensions should be isotropic (1 mm is optimal) with scan and reconstruction matrix of at least 256 × 256 (higher resolution is not necessary) to allow good overlays. The field of view should be skin to skin, that is, include the face, ears, and entire scalp (sagittal orientation of slice acquisition is best) such that an accurate identification of superficial fiducial points is possible for MEG to MRI coregistration.

The MEG-MRI coregistration method will vary depending on the type of MEG system and software package used.

Safety Precautions and Subject Comfort Issues

All provisions for subject safety including laboratory access/egress, equipment safety checks, emergency plans, personnel qualifications and competencies, and access to emergency medical care have to be implemented and have passed the Department of Health inspection, as appropriate.

Attention must be paid to the patients' comfort because it will also significantly affect the quality of recording. Standard approaches used with other neurodiagnostic testing should be implemented.

Sedation, including *general anesthesia*, is considered appropriate when necessary to obtain an adequate clinical MEG-EEG

recording. These procedures are always performed by an onsite specialized medical team that includes an anesthesiologist physician and/or other licensed provider qualified and credentialed in anesthesia/sedation. Sedation policies must conform with hospital rules on conscious sedation and/or general anesthesia depending on the procedure.

Quality Control of Localization Accuracy

The localization accuracy of source modeling software must be regularly verified using a phantom signal. Well-established physiologic landmarks, such as a short latency component of the somatosensory evoked fields (N20m), may be provide additional information for interpreting clinical studies relative to functional localization.

Data Storage and Management

Long-term storage and management of MEG-EEG data must comply with the current regulations regarding protected health information, medical records, studies, and tests.

Long-term storage should be of sufficient capacity to handle the projected annual volume of data with appropriate information security, backup, and data recovery. The capacity to store at least 60 minutes of spontaneous brain activity, acquired at the standard sampling frequency, must be available before beginning a clinical recording. A scheduled automatic backup of recorded data is recommended.

PREPARATION FOR MEG-EEG RECORDINGS

Technologists

Trained MEG-EEG technologists, under the supervision of a clinical magnetoencephalographer, should perform clinical MEG recordings.

Preparation

Accepted clinical procedures for neurodiagnostic studies must be followed in the preparation of an MEG-EEG study. In addition, the MEG-EEG technologist must be familiar with the procedures for preventing, identifying, and eliminating sources of MEG artifacts, including degaussing procedures. The need for advanced arrangements for turning off medical electronic devices, such as a vagus nerve stimulator, must be realized.

Subject and Data Monitoring

Spontaneous MEG-EEG signals change significantly according to the state of consciousness of the patient. Thus, a system for annotating the state of the patient, analogous to that used in EEG, should be implemented. This information aids accurate analysis, interpretation, and reporting by the clinical magnetoencephalographer.

Introduced Magnetic Noise and Its Prevention and Removal

The MEG-EEG technologist must make certain that all sources of magnetic noise are removed. This includes, but is not limited to, ferromagnetic materials on the subject including clothes and jewelry, hair sprays, make up, and the like. Having the patient routinely change into a hospital gown is the best approach. Sometimes a hair wash or skin cleaning may be necessary before an examination.

It may be an effective routine to degauss all subjects with known implants or other suspected sources of residual magnetization.

A commercially available handheld degausser should be used according to the manufacturer's instructions.

In cases where sources of unacceptable magnetic noise cannot be removed, such as with dental prostheses, cerebrospinal fluid shunts, or surgical implants and devices, the MEG recording may have to be aborted, if approved software for postacquisition artifact removal is not available. The clinical magnetoencephalographer and MEG–EEG technologist are responsible for making decisions regarding when to proceed, despite suboptimal recording situations.

Head Circumference Measurement

Because of a fixed head space in the MEG system helmet, it is worthwhile to measure the patient's head using a replica helmet before a study. Alternatively, this can be accomplished during an initial noise screening run, before electrodes are applied. It must be kept in mind that EEG electrodes, particularly when applied via EEG caps, may add to the head circumference significantly and lead to the inability to position the head appropriately in the helmet.

Screening Run

As a final preparation for a study, it may be useful to place the subject into the MEG system for a brief acquisition aimed at screening for sources of artifact.

EXAMINATION OF CHILDREN

Specifics of Recording Spontaneous Activity in Children

Generally, school age and older children may be sufficiently cooperative to be recorded without sedation. This is also true for infants who typically sleep after a feeding. However, toddlers, uncooperative, and/or developmentally delayed children often require sedation.

Recording spontaneous MEG–EEG during natural sleep is the preferred option, if attainable, because epileptiform activity is enhanced and untoward drug effects are avoided.

Utilization of *hypnotics* is not universally accepted as a means of sleep induction. If used, specific annotation of such should be made in the report. The presence of a parent or a staff member within shielded room may be necessary in this situation.

Sedation, including *general anesthesia*, may be necessary to obtain an adequate clinical MEG–EEG recording. These procedures are always performed by an onsite specialized medical team that includes an anesthesiologist physician and/or other licensed provider qualified in anesthesia/sedation, and MEG–EEG personnel should not be a part of this team.

Optimal Head Positioning

Particular attention must be paid to head positioning and fixation with children to obtain adequate recordings. Their small head size allows for significant movements within a conventional whole head MEG system helmet. Accordingly, these smaller heads should be carefully positioned and fixed using soft clothes, nonmagnetic padding, or nonmagnetic jelly-filled pads. For older children, it is often adequate simply to center the head in the helmet. Information regarding the head position must be appropriately recorded and documented at the time of the study and incorporated into the data

analysis. Real-time head position tracking systems, which are available with some advanced systems, are expected to minimize this problem. Currently, corrections for head motion in the source solution may be required for an accurate signal source estimation.

RECORDING OF SPONTANEOUS CEREBRAL ACTIVITY

Indications

Currently, MEG–EEG recordings of spontaneous cerebral activity are indicated and accepted for detecting abnormalities in background rhythms and identifying *interictal epileptiform discharges* (IIEDs) for the purpose of epileptic focus localization.

If a seizure is recorded during an MEG study ("an ictal MEG"), localization of the seizure onset is also indicated and accepted. However, differences in the generation of single interictal versus repetitive and evolving ictal discharges must be taken into consideration during source modeling. Because seizures can quickly propagate, only ictal waveforms or "spikes" at the onset of the seizure will likely reflect the location of the seizure origin.

Patient Monitoring

Spontaneous MEG–EEG signals change significantly according to the state of consciousness of the patient. Thus, an annotation system for patient state should be implemented to assist the clinical magnetoencephalographer in data analysis. If a digital annotation on the MEG recording is not available, a log sheet should be kept of the studies performed (spontaneous or evoked response) and any clinical events that occurred (seizure or excessive movement). It can also be helpful to note the beginning time of each study, the patient state during a given run (awake, drowsy, or asleep), whether epileptiform discharges occurred, and if so their general head location. A detailed and systematic annotation of artifacts that occur during the recording can provide invaluable assistance to the magnetoencephalographer during later interpretation of the record.

Simultaneous EEG Recording

It is highly recommended that EEG be recorded simultaneously with MEG. This should be considered a standard approach in epilepsy evaluations because these techniques provide complementary information and the highest yield when competently combined. It is recommended that EEG data be recorded using a common reference electrode, which will provide maximal reviewing and secondary processing flexibility. Magnetoencephalography compatible (i.e., nonmagnetic or minimally magnetic) EEG electrodes and lead wires should be used according to the well-established EEG practice.

The absence of simultaneous EEG recording for epilepsy recordings should be stated explicitly in the report, including its ramifications for clinical interpretation.

EEG Identification of Artifacts

Simultaneous recording of electrooculogram, ECG, and, at times, electromyogram is also necessary to aid identification of eye movements, muscle activity, and magnetocardiographic contamination and also to monitor the patient's state. Well-established EEG practice should be followed.

Video Monitoring and Recording

Video monitoring that includes an overview image of the patient in the MEG system is necessary for patient safety and to detect head/body movement. Additional close-up images of the patient's head may be helpful. Although not routinely available, synchronized recording of the patient video that follows well-established EEG practice may be of invaluable help during data interpretation.

Recording Duration

Minimum duration of spontaneous MEG-EEG recording sessions should be 30 minutes, and preferably, this will include both wakefulness and sleep. A longer recording is recommended if IIEDs are insufficiently frequent to permit a reasonable clinical interpretation. A repeated study with longer recording times, additional sleep deprivation, antiepileptic drug manipulation coordinated with the patient's epileptologist, sedation, or other clinically acceptable means for increasing diagnostic yield may be necessary.

RECORDING STATES

Standards established in the clinical EEG field should be followed to the degree that they are compatible with quality MEG recording.

Sleep Recording

Recording during sleep should be a standard part of a spontaneous MEG-EEG study for epilepsy because of the activating effect of sleep on IIEDs. Although natural sleep is preferable, sedative pills can be used with care to help ensure that sleep is obtained during the limited time of a study. Utilization of partial sleep deprivation, for example, limiting sleep to 4 hours or less the night before the MEG recording, is recommended as a preferred way to enhance sleep likelihood.

Hyperventilation

Hyperventilation is a standard activating procedure for clinical EEG for epilepsy studies, and it may be implemented during MEG-EEG study. However, the MEG can be contaminated by large artifacts caused by associated head movements. Thus, if hyperventilation is used, the MEG data immediately after hyperventilation may be most useful.

Drug Activation

Activating IIEDs by pharmacologic means is not universally accepted. Thus, if pharmacologic activation is used, appropriate expertise, procedure, and documentation have to be implemented in these situations.

GENERAL RECOMMENDATIONS FOR ANALYSIS OF SPONTANEOUS MEG-EEG RECORDINGS

The standard elements of spontaneous MEG-EEG data analysis include examination of the time series data and source analysis computations using accepted methods.

Visual Inspection of Time Series (Spontaneous Activity)

Waveforms of MEG and EEG ("raw data," original data as collected) for the entire recording should be visually examined, following the principles established for clinical EEG. Visual inspection

of time series is an obligatory initial step in the analysis of spontaneous MEG-EEG data that is aimed at the (1) identification of artifacts, (2) evaluation of overall data quality and integrity, and (3) identification of background rhythms, asymmetries and other background characteristics, and IIEDs, including morphologic and temporal characteristics, in both MEG and EEG. These findings should be evaluated and reported systematically for each study.

Filters

Use of filters is usually necessary to eliminate irrelevant biologic signals and the inherent noise of MEG system and environment.

The particular selection of a high-pass, low-pass, band-pass, and/or notch filters depends on the analysis to be performed and the characteristics of the MEG system used. This selection requires an appropriate conceptual understanding of the filtering method and practical experience in their use.

Most current analytical routines used for the analysis of spontaneous MEG-EEG data for localization of epileptic foci benefit from using high-pass filter of 1 to 4 Hz and low-pass filter of 40 to 70 Hz.

Artifact Removal

Some modern MEG systems are delivered with proprietary software for noise elimination based on a variety of methods. Understanding the method and consequences of its use is necessary regardless of the technique.

Generator Source Analysis

Introduction

Source analysis is used for estimating the location of the cortical generators of neuromagnetic activity of interest. For epilepsy studies, identified IIEDs are most often used for this purpose. However, source analysis of slow-wave activity or fast activity is currently under investigation and may become standard practice in the future, if proven useful. If a seizure is recorded during a study, the onset of the seizure may be localized using methods for spike analysis if the potential differences between interictal and ictal discharge generation are taken into consideration during source localization (refer Analysis of Seizures for more details).

Interictal Epileptiform Discharge Analysis

Source localization by the equivalent current dipole (ECD) modeling should be performed on all well-defined IIEDs; this includes spikes (20–70 milliseconds) and sharp waves (70–200 milliseconds). The clinical significance of both types of IIEDs in epileptic focus localization is equivalent.

The morphology, localization, and temporal characteristics of visually identified IIEDs should be reported in a standard fashion.

Although not routinely used by most clinical magnetoencephalographers, principal component analysis and independent component analysis can be useful to estimate the reasonable number of sources in the signal above background noise. If the background noise level has also been estimated, independent component analysis may be useful to identify and remove certain artifacts, such as ECG or eye movement artifact.

Analysis points in the interictal epileptiform discharge waveform. Several time points in the IIED waveform can be selected for source analysis. These include the spike peak or a point on the rising phase of the spike. Selecting the peak of

a large-amplitude spike will guarantee a high signal to noise ratio (SNR) that minimizes the calculation errors; however, the field at this latency may not represent the spike origin.

If an assessment of sequential field maps over a single spike phase shows no rotation, one can assume a stable source and model only at the spike peak for greatest SNR. If field rotation is evident, it is useful to model time points before the peak to seek an earlier source and throughout the spike time course to identify possible propagation. Note that modeling time points off the peak will mean lesser SNR and a larger confidence volume. This requires a more careful interpretation of the results. Cortical generators after the spike peak, such as the after coming wave, are typically complex and not well modeled by an ECD.

Head modeling for equivalent current dipole source analysis. The currently accepted clinical standard for the head model when analyzing MEG is a single sphere that best fits a three-dimensional reconstruction of the patient's head, derived usually from a volumetric MRI.

To minimize fitting errors, the sphere should include as much of the head in the area of interest as possible. It is legitimate and reasonable to use different spheres for the same subject to model separate sources in different parts of the brain.

Single equivalent current dipole model analysis. The ECD model is currently the most common and accepted method for modeling sources of IIEDs for the purpose of epileptic focus localization.

Assessment of magnetic isofield map. Evaluation of a magnetic isofield map at selected time points is necessary for estimating the number of generator sources and their spatial distributions. These maps will vary with the type of sensor coils in a particular MEG system.

When the magnetic isofield map at a selected time point contains a single, distinctive, dipolar pattern, a single ECD can be used to estimate the generator source. Multiple ECD analysis may have to be implemented if more complex fields are evident.

It is useful to view maps sequentially over the time course of the spike. If during a single phase of the spike, its magnetic field increases and decreases but does not rotate or change the shape, then one can assume a stable MEG source. If the field rotates during a single spike phase, the MEG source may be propagating.

Current moment. In the analysis of the IIED, the current strength (dipole moment) of the estimated single ECD may be helpful in determining whether a field transient is a likely physiologic source and not an artifact. Equivalent current dipoles with an estimated current strength (dipole moment) between 50 and 500 nAm are physiologic and thus potentially clinically relevant. Dipole sources outside of this range are sometimes rejected as probably artifactual. Regardless, making this distinction requires an understanding of the character of real cerebral sources, both normal and pathologic. One cannot rely on any single dipole parameter.

Anatomic and physiologic plausibility. Equivalent current dipoles that meet the above requirements (Assessment of Magnetic Isofield Map and Current Moment) still have to meet the requirement of anatomic and physiologic plausibility to be believable and, more importantly, clinically interpreted.

Interpretation of equivalent current dipole results. When interpreting ECD results, one must realize that an ECD is a theoretical simplified representation of activity over a considerable cortical area. Additionally, multiple closely spaced sources may produce what appears to be a single field, and thus they cannot be individually resolved.

Selecting specific channel groups for the purpose of modeling a particular source or a part of complex source is a legitimate approach; however, one must also realize that an inappropriate channel selection can lead to an incorrect source estimation.

Reliability of the single equivalent current dipole assumption. Certain solution parameters available with source modeling software (goodness of fit, total error, coefficient of correlation, and confidence volume) provide additional measures of the appropriateness of applying the single ECD to model given MEG-EEG data. For example, goodness of fit more than 70% is one frequently used criterion. However, none of these parameters can guarantee the appropriateness of the model. An understanding of the strengths and weakness of MEG dipole models, an appreciation of the character of cortical spike sources, and an implementation of practice recommendations will increase the likelihood of a correct model and source solution.

Multiple equivalent current dipole analysis (multiple dipole estimation). When an isofield map suggests the presence of multiple dipolar sources, an ECD estimation should be performed by selecting subsets of channels associated with each dipolar field, as long as their locations are sufficiently separated from each other. In these cases, multiple-dipole estimation methods, such as a 2-dipole model, should be implemented. Multiple dipole methods and interpretation require considerable experience and an appreciation for the greater likelihood of misleading solutions.

Analysis methods other than the dipole model. While widely used in research settings, other methods for source localization, including dipole scan models, distributed dipole models, current source density distributions, beamformer models, and the like, are not widely accepted for clinical purposes. If used, they should be accompanied by a standard ECD analysis of the same data. Furthermore, the MEG-EEG report must state which method(s) was used in data analysis.

Spike Averaging

Averaging a number of similar spikes will improve the SNR, minimize variability because of the background brain activity, and reduce the confidence volume of a resultant dipole model. However, averaging will also blur differences in location or time course of spikes from separate, but apparently similar, sources. Only spikes that possess similar field maps and field map evolution should be averaged. Averaging may also be used to find the "center of activity" of a cluster of individual spike dipoles (see Spike Clusters). Some instruments include software that identify and align spikes that are similar based on a template specified for the particular patient before averaging. However, at this point, there is no uniform agreement regarding the use of averaged spikes in clinical routine.

Number of Spikes

Although the frequency of IIEDs may indicate the severity of epilepsy and may have a predictive value for surgical outcome in

certain patient groups, algorithms for using these quantitative data have not been standardized in clinical epilepsy.

Currently, clinical spontaneous MEG-EEG is used principally to locate the foci of epileptic spike activity. No minimum number of spikes has been established as being necessary for clinical interpretation. However, it is suggested that sources for at least 5 spikes should be identified from a given patient. Obviously, consistent spikes with similar source model location and character would allow for more confident interpretation, even if the number was relatively small, whereas more spikes would be necessary, if their dipole models were more variable.

If spike frequency is low, their absolute numbers should be reported, otherwise qualitative frequency is acceptable. If multiple spike types with distinct foci are present, some measure of relative predominance should be provided.

Spike Clusters

The degree to which spike dipoles cluster in near vicinity to one another may be a useful parameter for identifying distinct foci and the relative activity of each. The center of such a spike dipole cluster provides information as to focus location; however, the size of the cluster is related to SNR and confidence volume of the individual spikes and not to the area of cortex involved. Currently, there are no widely accepted standards for the definition of, minimal criteria for, or additive clinical interpretation of spike clustering.

Spike Orientation

Consistent orientation of spike dipole models, as well as location, suggests a single cortical source. Given that dipole orientation is orthogonal to the net orientation of the source cortex, this parameter can therefore be used to identify the most likely source cortex in the region of the dipole. If there is no cortex of appropriate orientation near a model dipole, the accuracy of the model should be questioned. Final interpretation of spike orientation must be considered in the context of the patient's individual anatomy.

Comparative Analysis with EEG

Simultaneously recorded EEG serves several purposes in MEG/EEG analysis. An EEG can be more quickly reviewed for IIEDs given the lesser number of channels. This can shorten the time necessary to find MEG spikes for modeling. However, because some MEG spikes do not have an EEG correlate, the MEG should be reviewed separately and completely. Conversely, some EEG spikes that have a radial field will not have an MEG correlate. An EEG review can also identify epileptiform "normal variants" that should not be considered pathologic. The relative timing of MEG versus EEG spikes can be useful in characterizing propagation. If an EEG spike or spike peak follows that of the MEG, propagation from a tangential source to a radial source is likely. If the MEG spike lags that of the EEG, propagation from a radial to a tangential source is likely. Finally, because most patients with epilepsy will have had extensive previous EEG studies, the simultaneous collection of EEG allows the magnetoencephalographer to relate the MEG localizations to the patient's previous EEG studies for the clinical interpretation in the context of the patient's prior studies.

Analysis of Slow-Wave Activity

Sometimes, MEG and EEG slow waves have a dipolar character, and thus, they can be modeled. Not only is focal slowing seen with lesions but also it can also be seen in focal epilepsies. Temporal intermittent rhythmic delta activity is an example. Source

modeling of slow-wave activity, when it possesses a dipolar character, can provide more precise localization of the source than by simple visual inspection of the traces.

When nondipolar, MEG focal slowing may be commented on and taken into consideration in a final interpretation in much the same way as the focal EEG slowing is considered in traditional EEG interpretation.

Analysis of Seizures

Electrographic and/or electroclinical seizures may be recorded during an MEG-EEG study. Analysis of these ictal events can use methods similar to IIED analysis described above. However, ictal discharges may start as a lower amplitude fast activity rather than individual spikes. This lower amplitude activity may be difficult to localize with source modeling because of poor SNR. If attempted, inclusion of confidence volumes based on the SNR should be provided, or at least a notation of the low SNR should be given in the interpretation. If the ictal onset consists of repetitive spikes, sharp waves, or a higher amplitude ictal rhythm, consideration should be given to the fact that ictal activity can propagate rapidly into adjacent cortex. Accordingly, the earliest ictal potentials should be used for source modeling in seeking the location of seizure origin. In some cases, averaging repetitive ictal spikes or waveforms possessing the same field topography at seizure onset may enhance the SNR and reduce the confidence volume of the source solution.

Patients commonly move during a seizure, which can confound source localization and its coregistration with the brain MRI. If continuous head localization is not available, other indicators of patient movement should be used, such as muscle or movement artifact on the MEG or EEG, and every effort should be made to confine source solutions to the time before movement. As with video/EEG reports, a notation should be made in the body of the report and the interpretation regarding when the modeled ictal activity occurred relative to the electrographic and clinical seizure onset.

Coregistration of Magnetoencephalography Findings With Brain MRI

Referring physicians should receive MEG results in the form of EEG and MEG tracings of representative spikes or sharp waves used for source analysis in addition to magnetic source images that contain one dipole source localization and its moment per spike coregistered with the patient's brain MRI.

Methods of coregistration depend on MEG system and additional software used for source localization. Any approved, reliable, accurate, and established method of coregistration may be implemented.

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American Clinical Magnetoencephalography Society Clinical Practice Guideline 2: Presurgical Functional Brain Mapping Using Magnetic Evoked Fields*

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The following are “minimum standards” for the routine clinical recording of magnetic evoked fields (MEFs) in all age-groups.

Practicing at minimum standards should not be the goal of a magnetoencephalography (MEG) center but rather a starting level for continued improvement. Minimum standards meet only the most basic responsibilities to the patient and the referring physician.

These minimum standards have been put forth to improve standardization of procedures, to facilitate interchange of recordings and reports among laboratories in the United States, and to confirm the expectations of referring physicians.

Recommendations regarding Laboratory (Center) Environment and Preparation for MEG Recordings are detailed in the American Clinical Magnetoencephalography Society Clinical Practice Guideline (CPG) 1 : Recording and Analysis of Spontaneous Cerebral Activity, except for its EEG aspect that is not considered necessary (although may be helpful in trained hands) for MEFs (presurgical functional brain mapping).

GENERAL INDICATIONS FOR MEG EVOKED FIELDS IN PRESURGICAL FUNCTIONAL BRAIN MAPPING

Magnetoencephalography shares with EEG high temporal resolution, but its chief advantage in presurgical functional brain mapping is in its high *spatial* resolution. Magnetic evoked fields are therefore done for *localization*; unlike electrical evoked potentials (EPs), MEF latencies and latency asymmetries are not typically used to detect abnormalities.

Like other laboratory tests, it is important that clinicians involved in MEG acquisition and interpretation be informed of the indications for the various modalities of testing and of the clinical question to be answered. In return, the results of the MEG should answer the questions that prompted the referral. Both proper referrals and useful answers depend on timely and complete communication between the referring physician and the clinical magnetoencephalographer. Such communication may necessitate follow-up conversations to clarify indications or provide some education.

SPECIFIC INDICATIONS, METHODS OF ACQUISITION, AND ANALYSIS TECHNIQUES FOR MEG EVOKED FIELDS

Satisfactory localization of a magnetic evoked response depends on obtaining a satisfactory signal. All the MEFs depend on averaging to achieve an adequate signal in comparison with the background activity that is not related to the response, that is, an adequate signal to noise ratio (SNR). What constitutes an adequate SNR is not fixed but rather depends on the individual patient and the modality being tested. In general, an adequate SNR is determined by the appearance of a robust response based on the magnetoencephalographer’s experience. Ensembles containing too many trials can also be problematic. As noted in the “analysis” segments below, the SNR of the average can be improved by some or all of the following: noise cancellation applied to the raw signals, discarding noisy or otherwise corrupted trials, judicious use of time-domain or spatial filters. All these techniques rely on post hoc averaging from the continuously recorded raw data. While the number of trials that must be recorded to obtain a sufficient number of good ones is highly variable, the suggestions below provide ranges that are typical in clinical patients. Real-time averaging is used only as a rough indication that responses are being satisfactorily obtained but should not substitute for off-line (post hoc) averaging. These important points are reiterated in each of the acquisition and analysis segments below.

Somatosensory Evoked Fields

Indications

- Localization of somatosensory cortex (often in situations where there are large central lesions or other abnormalities in the vicinity of the expected central region).
- Localization of the central sulcus (in conjunction with motor evoked fields).
- Biologic quality check of coordinate transformation (spatial biocalibration).

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Stimulation

- Sites of electrical stimulation frequently used in clinical somatosensory evoked fields (SEFs) examination include the median nerve and tibial nerve, and mechanical stimuli can be used for fingers, lips, tongue, and other regions of the body.
- Electrical stimulation
 - Stimulus parameters: a constant current, monophasic rectangular pulse of 100 to 300 μ s should be used.
 - Somatosensory stimulus amplitude should be adjusted for the individual patient to exceed motor threshold (i.e., to cause a clearly visible twitch). Although sensory responses are produced at lower stimulation levels, setting the stimulation at 0.5 to 1 mA above the motor threshold ensures that sensory fibers are being stimulated. This procedure also provides an objective means to obtain reproducible sensory stimulation levels. Typical stimulus amplitudes required to achieve a twitch range from 5 to 10 mA.
 - Stimulation electrode impedance should be 5 k Ω or less.
 - The aggregate stimulus frequency should not be higher than 5 per second even if distributed to multiple stimulation sites.
 - Electrode placements for stimulation of a particular nerve should follow accepted guidelines established in the field of EPs, as described in the corresponding American Clinical Neurophysiology Society Guidelines.
- Mechanical stimulation
 - Devices include air puffs, pressurized bellows (sometimes incorporated into specialized gloves), handheld brushes consisting of an optic fiber bundle, and other electrically triggered devices.
 - Tactile stimulation may not produce results that are as reliable as electrical stimulation, but some centers have well-established routines using this type of stimulation, and they may be advantageous in infants and toddlers or in patients with impaired cognition.

Recording (Data Acquisition Based on Electrical Stimulation)

- Band pass of 0.03 to 300 Hz with a digitization rate of at least 1,000 Hz is preferred to facilitate postprocessing of the raw data.
- Recording the raw data is mandatory to permit discarding undesirable trials or channels post hoc.
- Real-time averaging is optional and may help to determine the number of necessary trials; 200 to 500 trials may be required to yield an adequate number of acceptable trials. Averaging off-line after data collection permits noise reduction processing and manual or automatic artifact rejection.
- Epoch duration of -50 ms to 250 milliseconds. Additional prestimulus baseline (e.g., back to -100 ms) may be useful for offset correction.
- Inter-stimulus interval (ISI) of 500 to 2,000 milliseconds (similar for mechanical stimulation).
- Stimulus channel indicators should be present and clearly labeled in the raw data to indicate stimulation triggers.
- Jitter less than 100 μ s.
- Head position measurement should be carried out before each ensemble or data block. Use of continuous head position tracking is preferred if available.
- The testing paradigm should be repeated to assess reproducibility and ensure consistent results.

Data Analysis

Averaging (based on electrical stimulation)

- Optional real-time averaging (i.e., during recording) can be helpful to obtain an estimate of the SNR.
- Recording of the raw data is mandatory, and the analysis system must permit post hoc averaging.
- The analysis system must permit inspection of raw data.
- 100 to 300 trials per stimulus location may be required to acquire an adequate number of acceptable repetitions.
- Off-line averaging after data acquisition permits
 - noise reduction processing,
 - elimination of artifact-containing traces, and
 - judicious selection of band-pass filtering (typical high-pass cutoff from 1 to 20 Hz and low-pass cutoff from 40 to 100 Hz).

Source localization

- During source analysis computations, the location of the N20m and/or P35m peaks should be fitted and their quality assessed by the localization difference between replications (usually in the range of 4–5 mm).
- Ensemble replications should differ from each other by less than 5 mm for N20m and P35m localizations.

Interpretation and Reporting of Somatosensory Evoked Fields

Addressed jointly for SEFs, motor evoked fields, auditory evoked fields (AEFs), and visual evoked fields (VEFs) in the section Interpretation and Reporting of MEG Evoked Fields.

Movement-Related Magnetic Fields and Motor Evoked Fields

Indications

- Localization of primary motor cortex in situations with rather large abnormalities (cystic encephalomalacia, polymicrogyria, etc. or smaller caliber abnormalities, space demanding processes in vicinity of the expected central region) before neurosurgical intervention or radiosurgical procedures.

Activity

- Motor functions evaluated and timing fiducial
 - finger tapping, self-paced
 - finger tapping, cued (visually, auditory)
 - light-beam interruption, switch closure, or another available time fiducial may be used as a timing indicator for averaging
 - repeated contractions with electromyogram (EMG) onset as a timing indicator for averaging, with or without tactile cuing
 - isometric contraction, simultaneous EMG.
- Note that the subject's level of consciousness must permit cooperation and task execution. Habituation and boredom often limit repetitions.
- Silent counting is not permitted, as this attenuates the movement-related magnetic field potential.

Recording (Data Acquisition)

- Band pass of 0.03 to 300 Hz with a digitization rate of at least 1,000 Hz is preferred to facilitate post-processing of the raw data.
- Recording the raw data is mandatory to permit discarding undesirable trials or channels post hoc.
- Real-time averaging is optional and may help to determine the number of necessary trials. 100 to 500 trials may be required to yield an adequate number of acceptable trials. Averaging off-line after data collection permits noise reduction processing and manual or automatic artifact rejection.
- Epoch duration and intermovement interval
 - finger tapping, self-paced, –500 to 200 milliseconds, intermovement interval 1 to 2 s
 - finger tapping, cued (visual, auditory), –500 to 200 ms, intermovement interval 2 to 3 seconds
 - repeated contractions with EMG, –500 to 200 ms, intermovement interval 2 to 3 seconds
 - isometric contraction, 240 s of isometric contraction (with short interruptions permitted)
- Stimulus channel indicators should be present and clearly labeled in the raw data to indicate stimulation triggers.
- Head position measurement should be carried out before each ensemble or data block. Use of continuous head position tracking is preferred if available.
- The testing paradigm should be repeated to assess reproducibility and ensure consistent results.

Data Analysis

Averaging

- Optional real-time averaging (i.e., during recording) can be helpful to obtain an estimate of the SNR.
- Recording the raw data should be mandatory, and the analysis system must permit post hoc averaging.
- The analysis system must permit inspection of raw data.
- Averaging with respect to the appropriate trigger (e.g., light beam interruption, EMG burst) must be selectable post hoc at the magnetoencephalographer's discretion.
- Off-line averaging after data acquisition permits
 - noise reduction processing,
 - elimination of artifact-containing traces, and
 - judicious selection of band-pass filtering (typical band pass of 1–25 Hz for finger tapping).
- Typical number of averages required to ensure adequate SNR are
 - finger tapping, self-paced, 70 to 100 each left and right
 - finger tapping, cued, 50 each left and right
 - repeated contractions with EMG, 70 to 100 each left and right
 - isometric contraction, calculating corticomuscular coherence.

Source localization

- Source analysis computations
- finger tapping, movement-related field approximately 30 to 40 milliseconds before movement onset.
- repeated contractions with EMG, movement-related field approximately 30 to 40 milliseconds before movement onset.
- isometric contraction, coherence peak at 20 Hz.

Interpretation and Reporting of Motor Evoked Fields

Addressed jointly for SEFs, motor evoked fields, AEFs and VEFs in the section Interpretation and Reporting of MEG Evoked Fields.

Auditory Evoked Fields

Indications

- Localization of primary auditory cortex on the superior temporal gyrus.
- Assessment of hearing in children.
- In contrast to electrical auditory EPs, the early latency signals (brainstem auditory evoked potential) are not well recorded by the MEG.

Stimulation

- Tones, typically 1,000 Hz, presented monaurally.
- Individual stimulus parameters, 80 to 90 dB sound pressure level (\sim 60 dB above hearing threshold), 50- to 200-millisecond duration.
- Interstimulus interval, typically 1 to 2 second ISI, jitter less than 100 μ s.
 - A longer ISI, up to 3 seconds may be required in children to obtain an adequate response.
 - In adults, the use of long ISIs may lead to a dual peak in the N100m response.
- Contralateral white noise masking at 40 to 50 db hearing level will prevent unintended cross-stimulation of the contralateral ear.

Recording (Data Acquisition)

- Band pass of 0.03 to 300 Hz with a digitization rate of at least 1,000 Hz is preferred to facilitate postprocessing of the raw data.
- Recording the raw data is mandatory to permit discarding undesirable trials or channels post hoc.
- Real-time averaging is optional and may help to determine the number of necessary trials; 200 to 500 trials may be required to yield an adequate number of acceptable trials. Averaging off-line after data collection permits noise reduction processing and manual or automatic artifact rejection.
- Epoch duration of –200 to 500 milliseconds.
- Stimulus channel indicators should be present and clearly labeled in the raw data to indicate stimulation triggers.
- Head position measurement should be carried out before each ensemble or data block. Use of continuous head position tracking is preferred if available.
- Patient must be awake. Therefore, adequate sleep of the patient before AEF testing is essential.
- The testing paradigm should be repeated to assess reproducibility and ensure consistent results.

Data Analysis

Averaging

- Optional real-time averaging (i.e., during recording) can be helpful to obtain an estimate of the SNR.
- Recording of the raw data should be mandatory, and the analysis system must permit post hoc averaging.
- The analysis system must permit inspection of raw data.
- Off-line averaging after data acquisition permits
 - noise reduction processing,
 - elimination of artifact-containing traces, and
 - judicious selection of band-pass filtering (as narrow as 1–30 Hz).
- Include sufficient trials to obtain a robust response, typically 100 artifact-free epochs.

Source localization

- Localize the N100m component of the AEF.

Visual Evoked Fields**Indications**

- Localization of primary visual cortex before neurosurgical resections.
- Assessment of abnormal visual function.

Stimulation

- Typically generated using specialized presentation computer with image shown on a back-projection screen.
- To eliminate partial visual field effects, computer graphics output cards, and projectors must be specially chosen for fast response.
- To eliminate timing errors or jitter (because of uncertainty of timing from computer, raster refresh rate, etc), a timing sync pulse (either from the stimulus computer or from an independent indicator such as a photocell) that is accurate to within 1 millisecond must be recorded by the MEG system.
- To assess the visual system, full-field, hemifield, and/or quadrant steady-state stimuli may be used; contrast, luminance, screen placement, check size, and field size to produce the appropriate subtended visual angle should follow the parameters used for conventional scalp visual evoked potential guidelines.
- Half-field checkerboard reversal pattern with 1-second ISI is the most common procedure.
- A fixation point should be provided. If patient cannot fixate well, full-field stimulation should be used.
- Adequate sleep of the patient before VEF testing is essential.

Recording (Data Acquisition)

- Band pass of 0.03 to 300 Hz with a digitization rate of at least 1,000 Hz is preferred to facilitate postprocessing of the raw data.
- Recording the raw data is mandatory to permit discarding undesirable trials or channels post hoc.
- Real-time averaging is optional and may help to determine the number of necessary trials; 200 to 500 trials may be required to yield an adequate number of acceptable trials. Averaging off-line after data collection permits noise reduction processing and manual or automatic artifact rejection.
- Epoch duration of –100 to 300 milliseconds.
- Stimulus channel indicators should be present and clearly labeled in the raw data to indicate stimulation triggers.
- Jitter less than 50 μ s.
- Head position measurement should be carried out before each ensemble or data block. Use of continuous head position tracking is preferred if available.
- The testing paradigm should be repeated to assess reproducibility and ensure consistent results.

Data Analysis*Averaging*

- Optional real-time averaging (i.e., during recording) can be helpful to obtain an estimate of the SNR.

- Recording of the raw data should be mandatory, and the analysis system must permit post hoc averaging.
- The analysis system must permit inspection of raw data.
- Off-line averaging after data acquisition permits
 - noise reduction processing,
 - elimination of artifact-containing traces, and
 - judicious selection of band-pass filtering (typical high-pass cutoff from 1 to 9 Hz and low-pass cutoff from 50 to 100 Hz).
- Include sufficient trials to obtain a robust response, typically 100 to 200 artifact-free epochs.

Source localization

- During source analysis computations, the location of the P100m should be identified.
- Ensemble replications should differ from each other by less than 5 mm for the localization of the P100m.

Interpretation and Reporting of Auditory Evoked Fields

Addressed jointly for SEFs, motor evoked fields, AEFs and VEFs in the section Interpretation and Reporting of MEG Evoked Fields.

Interpretation and Reporting of MEG Evoked Fields

Common aspects of reporting MEG–EEG studies are addressed in the American Clinical Magnetoencephalography Society Clinical Practice Guideline 3 (ACMEGS CPG#3): MEG–EEG Reporting.

General Considerations for Interpretation and Reporting of All MEFs

- When careful elimination of individual artifact-containing traces (either automatically or manually) does not produce an adequate average, off-line noise-reduction techniques or more restrictive band-pass filtering can often improve localization.
- MEFs are not indicated for diagnosis using measurement of absolute latencies or precise calculation of interhemispheric latency asymmetries. Response time measurements are only needed to properly identify the peaks that are to be localized.
- The primary sensory responses, with latencies similar to scalp EPs, should be identified. Latencies should approximate those for scalp EPs (if simultaneous EEG has been acquired, the electrical EP peaks can be used directly to help identify the magnetic responses within a given subject).
- These major components should be localized and coregistered with the patient's own MRI. Several source localization techniques exist and may be applied, as with other MEG signals. The single equivalent current dipole is an adequate model for MEG evoked fields.
- MRI image volumes with a 1-mm-slice thickness (e.g., MPRAGE, multiecho, or similar) are optimal for adequate localization. Skin to skin MRI head coverage is necessary for proper coregistration.
- Determination of head position, necessary for coregistration, requires digitization of the position of head coils, landmarks, and at least 100 additional points distributed over the head.

Special Considerations for Interpretation and Reporting of Specialized Evoked Fields

Movement-related fields

- Movement-related magnetic field responses are more difficult to reliably elicit than somatosensory responses (such as electrical median nerve stimulation). Therefore, for clinical testing using two different paradigms per patient may be needed to increase the yield.
- Weakness of distal hand muscles (because of perinatal stroke and the like) presents an additional challenge for successful movement related field localization.

Auditory evoked magnetic field

- Providing adequate auditory stimulation in older patients may be difficult. Obtaining a stimulus above an individual hearing level might be limited in this population as presbycusis may increase the hearing threshold level, and the auditory stimulation systems available for MEG laboratories may have a limited dynamic range.
- In addition, different ear inserts (foam plugs vs. open ear inserts) for monaural stimulation may produce different loudness levels. Documenting the dynamic range of the auditory stimulation system across attenuation levels should be part of the standard procedure manual of the MEG laboratory.

It is important that these considerations be kept in mind so that the report reflects the stimulation difficulty, if encountered, and is not misconstrued as an abnormality.

Data to be Included in the Report

Patient identification

- Facility name, laboratory name, address.
- Test date, test identification number, procedure name.
- Requesting physician's name, interpreting physician's name.
- Patient name, age, gender.
- Clinical information.
- Clinical question.
- Patient information that could influence results of the study, including behavior, medications, level of consciousness.

Technical data

- Standard stimulation and recording settings.
- Volume conductor model, source model, coordinate transformation.

Results

- Number of averages, reproducibility.
- Numerical descriptors.
- Pictorial/graphical representation of results.
 - Magnetic sources for responses that appear to be normal may be shown alone or in combination with other relevant sources (e.g., a motor response shown along with periorificial spike dipoles).
 - For nonprimary sensory responses (motor, language), and very abnormal looking signals of primary sensory responses, the graphical presentation of waveform should be considered part of the clinical documentation/report.

Description

- Deviation from normal location, as well as unusual waveforms and the like.

Interpretation

- Impression normal versus abnormal.
- Clinical correlation.

Language Evoked Magnetic Fields From Speech Comprehension and/or Production

Background

Linguistic stimuli presented acoustically or visually result in language-related responses (late responses) in addition to primary auditory and visual responses (early responses). Language-evoked magnetic fields (LEFs) appear after the primary sensory components and are generated in language-related areas of the brain regardless of the modality of stimulus presentation. Language-evoked magnetic fields are repeatable. Laterality of the language areas, as measured by MEG, has been found to correlate between 80% and 95% with results from the Wada procedure and mapping during intracranial recordings. Language-evoked magnetic field studies of receptive language (comprehension) localize sources to the posterior aspects of the superior and middle temporal lobe and the temporoparietal junction, whereas LEF studies of expressive language (speech production) localize activity in frontal and basal temporal areas.

The primary clinical application of LEFs is to determine the language-dominant hemisphere, which is particularly important because significant changes can result from anatomic and functional disorders. The results from these studies show that MEG LEF studies are able to replace the language portion of the invasive Wada procedure.

Indications

- Determining the language-dominant hemisphere in patients with either organic or functional brain diseases before surgical interventions, such as craniotomy, stereotactic or radiosurgical procedures; and/or
- Objective functional evaluation of language processing (i.e., identification of location and latencies).

Stimulation

- Computer systems for presenting language stimulation are the same as those used for eliciting AEFs and VEFs.
- Identification of the language-dominant hemisphere is accomplished by comparing results from language stimulation with those from nonlanguage stimulation.
- Enhancement of LEFs can be obtained in a task requiring the subject to recognize or categorize linguistic stimuli.
- Word comprehension and picture or action naming are tasks frequently used to evoke language processing. Most language stimuli are concrete nouns that can be presented visually or acoustically.
- *Auditory presentation.* Single word auditory stimuli are most commonly used, with fixed or random interstimulus intervals, typically greater than 2 seconds. Stimuli are typically presented at normal listening levels (~60 dB above normal hearing levels) and subjects may be asked to either listen passively to the words or to covertly (silently) think of an action word that goes with the word. Examples of the auditory stimuli can be found in Papanicolaou et al. (2004).
- *Visual presentation.* Visually presented words may also be used. Subjects can be asked to either read the words or they can be asked to read the word and think of an action word that goes with the word. Examples of the visual stimuli can be found in Bowyer et al. (2004).

- **State variables.** Before initiating the study of LEFs, it is necessary to confirm that the subject is in a state of wakefulness. This is critical for collecting data with a good SNR. The occipital alpha rhythm in spontaneous on-going MEG recordings can be used to monitor wakefulness during the study. The use of behavioral target stimuli interspersed in the task stimuli (e.g., push a button when you see a solid circle) can be used to determine if the subject is awake and participating in the task. The technologist running the study can watch the response channel to determine if the subject pushes the button. Data segments associated with target stimuli and lateralized motor responses should not be averaged in the final MEG evoked responses.

Recording (Data Acquisition)

- Band pass of 0.03 to 300 Hz with a digitization rate of 1,000 Hz is preferred to facilitate postprocessing of the raw data.
- MEG recording for language should be continuous.
- Triggers must be simultaneously recorded for segmenting data and averaging the evoked waveforms in postprocessing analysis.
- The data processing is similar to that used for all evoked responses.
- Online averaging runs the risk of including trials with large movement artifacts and/or eye blinks and should generally be avoided, or employed in real-time only to assess proper system operation.
- Head position measurement should be carried out before each ensemble or data block. Use of continuous head position tracking is preferred if available.
- Performance of the same task should be replicated during the same session. Independent analysis of the two data sets can help to minimize sources of error (i.e., head movement, changes in performance, attention level, variations in background activity, coregistration errors).

Data Analysis

Averaging

- When magnetic signals are small, continuously recorded data can be averaged off-line to improve the SNR.
- Averaging over the multiple time epochs is valid only when intracranial events are assumed to be identical.
- Adequate SNR for LEFs can be typically achieved with 50 to 100 artifact-free trials.
- Early evoked fields can be used for quality control (latency, topography). For example, if stimuli are presented acoustically, the auditory N100m responses should be symmetrical in topography, peaking around 100 milliseconds and with similar amplitude.
- Data should be typically band-pass filtered 1 to 50 Hz.

Initial inspection of data

- Before considering the analysis of long-latency language-related activity, it is important to evaluate the integrity of basic auditory/visual responses at ~100 milliseconds.
- Tumors and other lesions can cause lateralized compromise of basic sensory (auditory/visual) processing if located in primary or secondary sensory (auditory/visual) areas. If core sensory processing (auditory/visual) is compromised, special caution is needed in the interpretation of long-latency activity.
- Raw data used to generate averages should also be inspected. Lateralized paroxysmal spikes, sharp waves, and slow waves can have a dramatic effect on evoked responses and lead to

misinterpretation of laterality profiles. Epochs with such activity must be discarded from the averaging process. In some cases, continuous lateralized slow wave activity may be present. Unless this can be selectively removed via signal processing strategies (e.g. the Signal Space Projection, Independent Component Analysis), one should not attempt to interpret language evoked fields.

Language evoked activity

- Long-latency responses (greater than 200 milliseconds in latency) evoked by language stimulation contain activity arising from multiple language areas, independent of the method of stimulation, auditory or visual. Such responses are enhanced when attention to the task is displayed. The signals reflect varying contributions from multiple language areas, including Wernicke's language area (superior temporal gyrus), Brodmann area (BA 22), the angular gyrus (BA 39), the supramarginal gyrus (BA 40), and Broca's language area (pars opercularis and pars triangularis of the inferior frontal gyrus [BA 44 and 45]). Different tasks appear to change the source regions that dominate the evoked responses.
- In general, the evoked LEF waveform will have several peaks. The initial peaks (<150 milliseconds) are generally associated with basic sensory processing in the modality of stimulation. Activity between 150 and 250 milliseconds is believed to be associated with feature processing and integration, with later activity reflecting high-order processing, including language. Regardless of the modality of stimulation and subtle details of the stimulation paradigms, linguistic stimuli evoke a large, typically lateralized, response that normally peaks between 400 and 500 milliseconds. The activity may begin as early as 250 milliseconds and may extend to 750 milliseconds or beyond.

Hemispheric dominance for language

- The determination of hemispheric dominance for language is based on an assessment of how much language activity is evoked in each hemisphere, as assessed by the language evoked field.
- Several strategies are available for source assessment, including single and multiple dipole based strategies, and current reconstructions such as L1 norm, L2 norm, or MR-FOCUSS, and beamformers. Different laboratories have used different methods, but the most commonly used methods are based on dipoles and minimum norm estimates.
- One of the most commonly used methods is to use single moving dipoles to account for the activity beyond 150 milliseconds. In this method, at each time point, a restricted sensor array is identified encompassing the long-latency response(s). A single equivalent current dipole is calculated and if the goodness of fit exceeds a prespecified criteria (e.g., 90%), then the fits are considered valid and the dipole is retained. After all time points are fit (typically in 1-millisecond steps), a laterality index is calculated based on the number of valid dipole fits in each hemisphere. Here, laterality index is defined by $100 \times (R - L)/(R + L)$, where L and R are the number of accepted dipoles fit in the left and right hemispheres, respectively. Laterality index values from -100 to -20 indicate strong left hemisphere language dominance. Laterality index values from -19 to +19 indicate bilateral language activation. Laterality index values from +20 to +100 indicate right hemisphere language dominance.

- The task should be repeated to ensure replicability of the derived waveforms, localizations, and laterality indexes. In the same recording session, the use of similar tasks in visual and auditory modalities is recommended helping to dissociate modality-specific activity from language-specific activity.
- A common alternative method is to use a distributed source model (e.g., MR-FOCUSS) and compare the integrated amount of current in left and right hemispheres over the LEF time window. This can be done across all activated regions, or specified regions (e.g., basal temporal areas). Here too, it is common to derive a laterality index, based on source signal strength as opposed to number of dipole fits.
- Alternative analyses, including beamforming strategies and multiple dipole strategies, may also be viable. The key is to integrate information over the long-latency time window and to examine data within the context of a source model that accounts for the subject's physical position relative to the sensors.

Interpretation and Reporting of LEFs

- Common aspects of reporting MEG–EEG studies are addressed in the American Clinical Magnetoencephalography Society Clinical Practice Guideline 3 (ACMEGS CPG#3): MEG–EEG Reporting.
- General interpretation and reporting principles for evoked fields are outlined in the section Interpretation and Reporting of MEG Evoked Fields and should be followed.
- At a minimum, the stimulus conditions and method of data analysis should be described. When calculated, the laterality index should be stated, along with a clear statement of which hemisphere is language dominant (left dominant, right dominant, bilateral, and inconclusive).
- Plotting of language-related data on spatially aligned MRI is at the discretion of each site and should be based on their experience concerning the reliability of localization information. Such plots may give the impression to neurosurgeons that areas without plotted activity are safe to resect. This type of error (false-negative) cannot be excluded systematically, so qualifying statements may be appropriate.

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American Clinical Magnetoencephalography Society Clinical Practice Guideline 3: MEG–EEG Reporting*

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for the ACMEGS Clinical Practice Guideline (CPG) Committee***

(*J Clin Neurophysiol* 2011;28: 362–363)

This guideline should be considered in the context of other American Clinical Magnetoencephalography Society (ACMEGS) guidelines that are conceptually similar to the sets of guidelines defined by the American Clinical Neurophysiology Society (<http://www.acns.org/>) for EEG.

MEG–EEG REPORTING

MEG–EEG reporting guidelines are not meant to represent rigid rules but general recommendations for reporting MEG–EEG results. They are intended for standard MEG–EEG recordings rather than for special procedures. When reporting on more specialized types of records, description of technical details should be more complete than in the case of standard recordings.

The MEG–EEG report should consist of the following principal parts: (1) patient identification information and clinical history; (2) MEG–EEG acquisition; (3) methods of analysis; (4) description of significant MEG and EEG findings; and (5) interpretation of findings, including impression regarding its normality or degree of abnormality and conservative correlation of the MEG–EEG findings with the clinical picture.

Patient Identification Information and Clinical History

This introductory segment of the report includes pertinent patient information and sufficient details from clinical history to clarify referral question(s) so that the clinical magnetoencephalographer can provide an optimally useful interpretation of the data. This segment of the report may be generated by an appropriately trained technologist or other ancillary personnel.

*Revisions of the document authored by the task force were made and the final version was approved unanimously by the ACMEGS Board (Anto I. Bagić, Gregory L. Barkley, Richard C. Burgess, Michael E. Funke, Robert C. Knowlton, Jeffrey D. Lewine) on December 18, 2010.

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MEG–EEG Acquisition

Details regarding the technical aspects of the recording and patient preparation should be described in this section of the report. These should include type of MEG system, number of channels, types of sensors, and number and duration of individual data collection runs. Specifics of EEG electrode placement, medications used in conjunction with the study, and problems with acquisition should be included.

Additional specifics related to the acquisition of magnetic evoked fields (specifications of stimuli and their presentation, stimulation sites where appropriate, number of averages, and number of replications) should be described if used.

An institution-specific template may be used if recording techniques are standardized.

Methods of Analysis of Spontaneous Activity and Magnetic Evoked Fields

All methods used in the analysis of spontaneous MEG–EEG and of magnetic evoked fields should be clearly stated in this part of the report. Currently accepted methods of analysis of spontaneous MEG–EEG activity are detailed in ACMEGS Guideline 1, 2011, “Recording and Analysis of Spontaneous Cerebral Activity” (Bagić, Knowlton, Rose, and Ebersole, 2011), and accepted methods for evoked magnetic field analysis can be found in ACMEGS Guideline 2, 2011, “Presurgical Functional Brain Mapping Using Magnetic Evoked Fields” (Burgess et al, 2011).

Description of Significant MEG and EEG Findings

This section of the report should include a separate description of all noteworthy features of the MEG and EEG, as well as comments regarding the spatiotemporal relationship between the two. Both normal and abnormal findings from a visual examination of spontaneous activity should be described in an objective way and without judgment about their significance.

Subsequently, the results of MEG spike and/or seizure source analysis should be presented clearly and concisely, as described in ACMEGS Guideline 1, 2011. The source estimate “goodness of fit” should be described in general terms, if not quantitatively. If simultaneous EEG source analysis is performed, these findings should be similarly described and the relationship between MEG and EEG source models should be discussed. At a minimum, the correlation between MEG source analysis and EEG visual inspection should be provided.

In a similar fashion, a description of averaged magnetic evoked field data, their reliability/reproducibility, and source modeling results should be provided, if these tests are performed.

Interpretation of MEG–EEG Findings

This part of the report is most frequently read by the referring physicians, who may have a less technical background. Accordingly, it should be phrased using clear and commonly understandable terms.

Impression Regarding Normality or Degree of Abnormality

The report should state clearly if the recording was normal or abnormal, and if the latter, the specific reasons for it is being considered abnormal. Usually, a report of a normal recording does not require further clarification.

Correlation of the MEG–EEG Findings With the Clinical Picture

The clinical correlation should be an attempt to explain how the MEG–EEG findings relate to the total clinical picture and to what degree these findings answer the referral questions. This explanation should be relayed in terms familiar to the referring physician.

For a spontaneous MEG study done as a presurgical evaluation, the use of the phrase, “clinical correlation necessary” is considered insufficient. Additional, clinically relevant information must be provided because source localizations may guide intracranial electrode placement. Interictal discharges, and when available ictal rhythms, should be described as focal, multifocal, or generalized at a minimum. Source lateralization and localization, in terms of lobar or sublobar area, should be summarized. Any propagation of interictal or ictal activity should also be described. In addition, this part of the report should state whether the MEG–EEG source localization is consistent with the presumed focus based on previous EEG findings and the patient’s seizure semiology. If disparate, plausible reason(s) for the difference should be provided. Furthermore, the anatomic relationship of MEG–EEG source estimates to any MRI lesion should be described.

Similarly, for an evoked magnetic field study done as part of a presurgical evaluation, the use of the phrase, “clinical correlation necessary” is considered insufficient. MEG–EEG localizations of eloquent cortex may also influence intracranial electrode placement, and the proximity of eloquent cortex to the presumed epileptogenic focus may influence the decision of whether to proceed with further surgical evaluation or surgery. It is important to indicate any deviation from the expected physiologic location of eloquent cortex and to describe the anatomic relationship of source estimates to any MRI lesion.

For presurgical evaluations of either spontaneous MEG–EEG or evoked fields, it may be reasonable to include specific recommendations for the referring physician, if clearly supported by the data and the clinical history available to the clinical magnetoencephalographer.

CONCLUDING REMARKS

At minimum, the referring physicians should receive MEG results in the form of magnetic source images that contain dipole source localizations coregistered with the patient’s brain MRI, in addition to the described narrative.

It is strongly recommended that examples of raw MEG–EEG traces and topographic field maps depicting the reported abnormalities be included. This includes both spontaneous and averaged evoked MEG–EEG data. The use of a specific symbol for each mapped modality on magnetic source images is necessary if more than one is depicted on the same image.

Because an MEG–EEG clinical report is used to guide clinical care and particularly presurgical epilepsy planning, the official report must be reviewed and signed by a clinical magnetoencephalographer (ACMEGS Guideline 4, 2011, “Qualifications of MEG–EEG Personnel” [Bagić, Barkley, Rose, and Ebersole, 2011]) to ensure clinical appropriateness and relevance in the clinical care setting.

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American Clinical Magnetoencephalography Society Clinical Practice Guideline 4: Qualifications of MEG–EEG Personnel*

*Anto I. Bagić,† Gregory L. Barkley,‡ Douglas F. Rose,§ and John S. Ebersole,||; for the
ACMEGS Clinical Practice Guideline Committee***

(*J Clin Neurophysiol* 2011;28: 364–365)

This Clinical Practice Guideline pertains to currently approved, reimbursable, clinical indications for magnetoencephalography (MEG), namely, localization of epileptic foci in surgical candidates with medically refractory epilepsy and functional mapping of eloquent cortices in preparation for surgery of various operable lesions. As new applications are clinically validated and established, the guidelines will be revised as needed.

QUALIFICATIONS OF MEG–EEG PERSONNEL

Minimal Qualifications for Physicians Interpreting Clinical Magnetoencephalography and MEG–EEG Studies

During the pioneering days of clinical MEG, many highly competent professionals of different background propelled the field, advanced clinically with it through different experiences, and currently interpret clinical MEGs within the team while not individually meeting the requirements listed below. A new phase of clinical MEG requires uniform educational standards proposed for individuals entering the clinical MEG field after 2010.

1. A doctoral-level professional interpreting clinical MEG and/or MEG–EEG studies should be a physician preferably with board eligibility or certification in neurology, pediatric neurology, or neurosurgery. Physicians from other specialties need to obtain additional exposure to clinical neurophysiology equivalent to the requirements for board

certification in this subspecialty (see point 2). All physicians interpreting clinical MEG and MEG–EEG studies need to acquire expertise specifically in MEG through additional supervised training (see point 3) and have an appropriate license for the practice of medicine.

2. Additional background training of physicians interpreting clinical MEG and MEG–EEG studies should meet the minimal requirements for examination by the American Board of Clinical Neurophysiology (www.abcn.org) or the American Board of Psychiatry and Neurology Added Qualifications in Clinical Neurophysiology (www.abpn.com).
3. Specific MEG training should also include supervised learning of and practice in clinical MEG recording, reviewing, and source analysis of clinical MEG for at least 6 months and the independent interpretation and reporting of at least 50 MEG studies of epilepsy and 25 MEG studies of evoked fields (auditory, visual, somatosensory, motor, and language). The majority of epilepsy studies should be abnormal and include a mixture of clinical findings.

Minimal Qualifications of Magnetoneurodiagnostic Technologists

1. The background qualifications of magnetoneurodiagnostic technologists shall preferably be those set forth for electro-neurodiagnostic technologists by the American Clinical Neurophysiology Society and allied organizations. Registries in electroencephalographic or evoked potential technology (REEGT and REPT), administered by the American Board of Registration of Electroneurodiagnostic Technologists (www.abret.org), are preferred for MEG technologists. Technologists of related disciplines need to acquire additional exposure to and training in clinical neurophysiology.

2. At least 6 months of supervised clinical experience in an active MEG center, following formal training, is suggested to record MEG–EEG in an unsupervised capacity.
3. A minimum of 3 of the 6 months should include additional supervised training in the principles of MEG technology, technical aspects of MEG systems with competency in operational routines, including helium filling, tuning procedures (as applicable), standard testing procedures, trouble shooting, artifact prevention and elimination, data storage, and sufficient understanding of source localization to preprocess routine clinical data for the analysis by a physician magnetoencephalographer.

*Revisions of the document authored by the task force were made and the final version was approved unanimously by the ACMEGS Board (Anto I. Bagić, Gregory L. Barkley, Richard C. Burgess, Michael E. Funke, Robert C. Knowlton, Jeffrey D. Lewine) on February 2, 2011.

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Laboratory (Center) Organization and Reporting of Studies

1. The laboratory (center) director shall have the primary responsibility for the overall operations and policies of the laboratory (center). These policies should be documented in written form in a policy and procedures manual. Under the supervision of the MEG laboratory (center) director, the chief MEG technologist shall be responsible for the daily operation of the laboratory (center). The chief technologist or a designated technologist, together with the laboratory (center) director, shall ensure that the highest standards of MEG-EEG technical practice are maintained.
2. All clinical MEG and MEG-EEG studies should be analyzed, interpreted, and signed by a qualified physician magnetoencephalographer, and co-signatures by an unqualified physician are considered inadequate on clinical reports.
3. The processing and analysis of magnetoencephalograms requires considerable time and skill to complete satisfactorily. In most centers, nonphysician MEG scientists with a doctoral degree in biological sciences and neurophysiological training are expected to help with the processing of MEG data. Technologists, neurologists in training, and physicians from other disciplines with appropriate backgrounds in clinical neurophysiology and MEG also help with the processing of MEG data in most centers. While the assistance of such personnel is critical to the operation of a MEG laboratory (center), only

physician magnetoencephalographers should have the primary responsibility for clinical interpretation of MEG-EEGs.

4. Records should be maintained in an orderly manner and stored according to an established EEG practice.

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Disparities in Clinical Magnetoencephalography Practice in the United States: A Survey-Based Appraisal

Anto I. Bagić

Purpose: To investigate institutional and individual practices and attitudes in clinical magnetoencephalography (MEG) in the United States.

Methods: An MEG Center Director Survey (20 questions) and an MEG Center Doctoral-Level Staff Survey (6 questions) were e-mailed to all clinically active MEG centers in the United States (21) in 2008.

Results: Fifteen centers declared to be in operation an average of 7 years (range, 2 to 21 years), performing a total of 836 evoked field mappings, 842 epilepsy, and 1,222 research studies in 2006, and 866, 880, and 1384 such studies, respectively, in 2007. All sites claimed to use EEG in conjunction with MEG for epilepsy studies. The number of averages required for various evoked field modalities varied significantly among centers. In two centers MEG reports were signed by nonphysicians and in two other centers by nonneurologists. Epilepsy studies are reported within an average of 9.3 days (range, 1 to 30 days) and mapping studies within 4.1 days (range, 0.5 to 30 days). Thirty-two doctoral level survey participants (23 MDs and 9 PhDs) claimed an average of 9.6 years experience in MEG and average of 7.5 years in clinical MEG. More than five years experience in MEG was claimed by 18 participants, and more than 5 years experience in clinical MEG was claimed by 16. Eighty-eight percent of participants agreed that there was a lack of accepted clinical standards for MEG practice. Seventy-eight percent of neurologists and 75% of foreign medical graduates favored developing standards. Twenty-eight percent of participants and 100% of radiologists were not in favor of developing standards of MEG practice. Some form of certification for MEG practitioners was supported by 81% of participants.

Conclusions: Existing disparities in the current practice of clinical MEG in the United States necessitate clinical practice guidelines.

Key Words: certification, clinical practice, clinical practice guidelines, magnetoencephalography (MEG), magnetic source imaging (MSI), magnetoencephalography, standards of practice, training.

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Calling a magnetoencephalography (MEG)/magnetic source imaging (Cohen, 1968) a “new” or “investigational” technology 40 years after the first MEG recording (Cohen, 1972) is not only factually wrong but also unsupportable given that much younger and far less scrutinized technologies are considered clinical routine (Ducassou et al., 1980; Lenzi et al., 1981; Ogawa et al., 1990). Whole head MEG systems are a reality in most American MEG centers (Funke et al., 2009). Ample clinical evidence supporting MEG’s clinical usefulness is being published (Knowlton et al., 2008a, 2008b; Knowlton et al., 2009; Sutherling et al., 2008). A dedicated clinical

society (American Clinical Magnetoencephalography Society) reached its fifth anniversary, and its sustained efforts have made major improvements in insurance coverage policies for MEG (Bagić et al., 2009). The time is ripe to recognize the viability of and progress made in clinical MEG.

In pursuing its primary goal of promoting the highest standards in MEG clinical practice (Bagić et al., 2009), the American Clinical Magnetoencephalography Society appointed a Clinical Practice Guidelines Committee during its annual meeting in Boston (2008). A comprehensive survey of the prevailing clinical MEG practices in the United States was considered a necessary preparatory step before creating Clinical Practice Guidelines.

MATERIALS AND METHODS

All MEG centers in the United States (32) were contacted via e-mail and/or phone calls. Those centers with an ongoing clinical MEG service for the past two years were asked to participate in this survey. Directors of these MEG centers and all doctoral level staff were asked to complete the MEG Center Director(s) Survey (Appendix 1; 20 questions) and the MEG Center Doctoral-Level Staff Survey (Appendix 2; 6 questions). Only basic descriptive statistics were used to analyze data collected in these two surveys.

RESULTS

MEG Centers Survey Results

Twenty-one MEG centers in the United States were confirmed to be clinically active, 2 were thought possibly to be clinically active but were not reachable, and 9 were not clinically active in 2008. Directors of 19 clinical MEG centers returned the survey; however, only 15 of these centers had been in operation for at least 2 years. Only data from these established 15 centers were used in this report. These MEG centers declared a total of 106 years in operation (mode 4; Appendix 1; Question 1; Table 1).

The MEG center staffing varied considerably (questions 2–5; Appendix 1, data not shown) from minimal (a technologist and a doctoral-level study interpreter) to 10 or more full time equivalents in centers with large research and clinical programs. Centers focused only on epilepsy often had smaller staffs than those that were research oriented. However, the majority of the centers included more than one doctoral-level study professional. In 2 of the 15 centers, clinical epilepsy studies were interpreted and reports signed by nonphysicians, and in 2 of the 15 centers, clinical epilepsy studies were interpreted by a nonlicensed foreign medical graduate and reports signed by a neuroradiologist. In the remaining centers (11 of 15), an epileptologist or neurophysiologist interpreted and signed the report that was prepared mostly by them or rarely by other doctoral-level professional.

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TABLE 1. Cumulative Answers to MEG Center Director's Survey Questions 1, 6 to 8, 12, and 16

| Question | N | Total* | Mean | Minimum | Maximum |
|--|----|--------|------|---------|---------|
| 1. Duration of center's operation (years)† | 15 | 106 | 7 | 2 | 21 |
| 6. Annual number of clinically indicated and billed epilepsy localization studies in | | | | | |
| 2006 | 15 | 842 | 53 | 0 | 195 |
| 2007 | 15 | 880 | 59 | 5 | 189 |
| 7. Annual number of clinically indicated and billed pre-surgical MEG mappings counting each modality individually in | | | | | |
| 2006 | | | | | |
| AEF | 15 | 138 | 9 | 0 | 45 |
| LRF | 15 | 211 | 13 | 0 | 76 |
| MRF | 15 | 140 | 9 | 0 | 46 |
| SEF | 15 | 317 | 20 | 0 | 62 |
| VEF | 15 | 30 | 2 | 0 | 11 |
| 2007 | | | | | |
| AEF | 15 | 110 | 7 | 0 | 35 |
| LRF | 15 | 228 | 14 | 0 | 87 |
| MRF | 15 | 149 | 9 | 0 | 56 |
| SEF | 15 | 347 | 22 | 0 | 67 |
| VEF | 15 | 32 | 2 | 0 | 9 |
| 8. Annual number of research MEG studies in | | | | | |
| 2006 | 15 | 1222 | 76 | 0 | 340 |
| 2007 | 15 | 1384 | 87 | 0 | 340 |
| 12. Within how many days do you usually report clinical studies? | | | | | |
| Epilepsy | 15 | 150 | 9.3 | 1 | 30 |
| Mapping | 15 | 66 | 4.1 | 0.5 | 30 |
| 16. How many accepted average responses do you usually require for each modality being mapped?‡ | | | | | |
| AEF | 13 | 2080 | 160 | 100 | 400 |
| LRF | 12 | 2560 | 213 | 50 | 930 |
| MRF | 13 | 2340 | 180 | 80 | 740 |
| SEF | 15 | 2316 | 154 | 100 | 768 |
| VEF | 13 | 2350 | 181 | 100 | 512 |

AEF, auditory evoked field; LRF, language-related field; MRF, motor-related field; SEF, somatosensory evoked field; VEF, visual evoked fields.

*Rounded to the nearest whole number where appropriate.

†Only centers that were in operation for at least 2 years are included.

‡Only those who perform a respective modality.

Surveyed centers performed a total of 842 epilepsy localization studies (Fig. 1), 138 auditory evoked fields, 211 language-related fields, 140 motor-related fields, 317 somatosensory evoked fields (SEFs), and 30 visual evoked fields in 2006. Comparable data for 2007 included 880 epilepsy studies, 110 auditory evoked fields, 228 language-related fields, 149 motor-related fields, 347 SEFs, and 32 visual evoked fields (questions 6 and 7) (Table 1). These 15 U.S. centers also performed 1,222 research MEG studies in 2006 and 1,384 in 2007 (question 8, Table 1).

All centers claimed to use EEG while analyzing and interpreting a clinical epilepsy MEG study (question 9). Five centers used EEG to find MEG spikes that were then modeled with dipoles. Seven centers reviewed and modeled MEG independently of EEG but also reviewed EEG for spikes and modeled any MEG correlates. Three centers reviewed and modeled independently both MEG and EEG spikes.

Nine centers routinely used the equivalent current dipole (ECD) as the only source modeling method (question 10), 1 center combined the ECD with beamformers, 2 centers combined ECD with other methods (not beamformers), and 3 centers combined

ECD, beamformers, and other methods. Eleven centers relied (question 11) on proprietary MEG software, whereas 4 centers used both proprietary and commercial software.

On average, MEG centers completed the report of a clinical epilepsy study within 9 days and the report of presurgical mapping studies within 4 days (question 12, Table 1).

When mapping language function(s) (question 13), 6 centers used a silent naming paradigm, 3 centers used silent reading, 5 centers used dichotic listening, 8 centers used “other” methodology, and 1 center did not provide this service.

None of the centers claimed MEG recording for epilepsy localization of less than 30 minutes (question 15). One center recorded only 30 minutes, 12 centers for 30 to 60 minutes, and none for greater than 60 minutes. Two laboratories stated that the duration of acquisition depended on the number of spikes identified during recording.

The number of averages used to obtain evoked fields for each modality varied considerably (question 16). The mean number of responses averaged were 160 for auditory evoked fields, 213 for language-related fields, 180 for motor-related fields, 154 for SEFs, and 181 for visual evoked fields (question 16; Table 1).

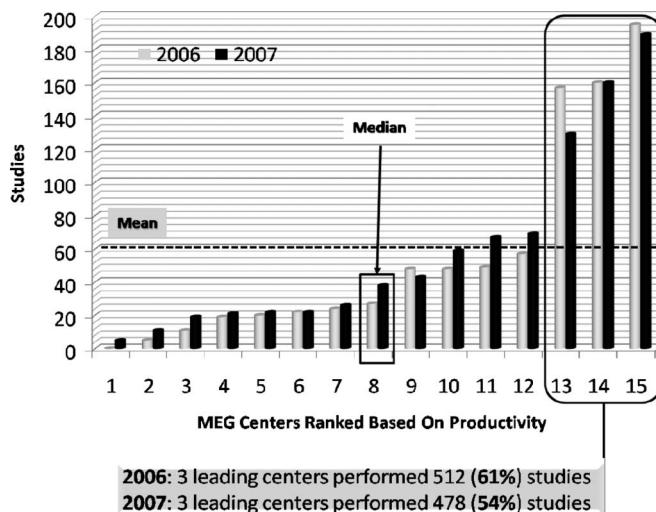


FIG. 1. Clinical epilepsy MEG studies performed by each participating USA center in 2006 and 2007.

Questions 17 to 19 were considered redundant between the 2 surveys and are not reported. The average time needed to complete the survey (question 20) was 9 minutes (range, 5.0 to 60.0 minutes).

Doctoral-Level Individual Professional Surveys Results

The survey was completed by 14 neurologists, 9 of whom claimed epilepsy and clinical neurophysiology expertise, 3 and 1 of whom stated epilepsy or neurophysiology expertise, respectively. Four radiologists, 1 psychiatrist, 9 doctorials, and 4 nonlicensed foreign medical graduates also completed the survey (question 3) (Fig. 2).

The participants collectively claimed a total of 307.5 years experience in MEG (question 1) and 241.5 years in clinical MEG (question 2) (Table 2). More than 5 years experience in MEG and in

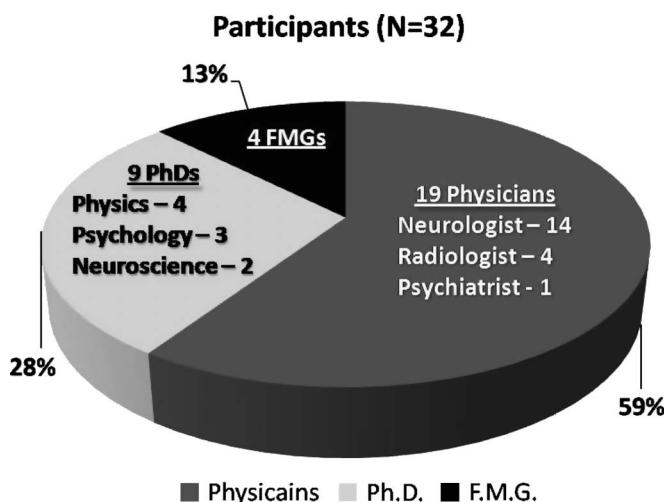


FIG. 2. Educational Profile of Doctoral-level Professional Survey Participants.

clinical MEG was claimed by 18 and 16 participants, respectively (Fig. 3).

The majority (28 of 32) agreed that "there are no accepted clinical MEG standards," 3 were "not sure if clinical MEG standards exist," and 1 participant did not answer the question (question 4) (Table 3).

When defining "attitude toward establishing clinical MEG standards" (question 5) (Table 4), 2 participants claimed that "everybody in the field knows the standards," 18 stated that "we need accepted standards as soon as possible," 7 stated that "standards would not change what we do," 3 decided to provide only a comment, and 2 simply "did not care." No one selected the answer "I know what I am doing and need no standards."

With regard to "attitude toward formalized certification" for interpretation of clinical MEG studies (question 6) (Table 5), 14 responders believed that "certification would improve the quality of patient care and help propel clinical MEG but should not be mandatory," 12 "would welcome an appropriate form of standardized training *with* certification," 4 "would welcome an appropriate form of standardized training *without* certification," 3 "opposed certification because it is just an unnecessary intricacy of the medical profession," 1 believed that "certification is a formality that would have no practical effect on the MEG field," and 1 participant decided to comment without selecting an answer.

DISCUSSION

This study has its obvious limitations and biases. Only the most motivated and reachable professionals completed the survey, and as an e-mail enquiry, it was not anonymous. This survey cannot account for any discrepancy between what was declared and what is being practiced. However, it is likely that this sample captured adequately the prevailing practices in clinical MEG centers in the United States because the directors of 19 of 21 centers responded. Regardless, our questionnaire underwent no validation, and the numbers are small. Accordingly, sophisticated statistical analysis seems unwarranted.

We reached 21 sites who confirmed ongoing clinical MEG service, and their participation rate exceeded 90%. At the time of the survey (2008), the only 2 (<10%) existing centers with known active clinical MEG programs did not participate. Thus, the survey likely reflects well the reality of the clinical MEG field in the United States.

TABLE 2. Claimed Overall and Clinical MEG Experience in Each Group

| | N (%) | Total | Mean | Minimum | Maximum |
|----------|----------|-------|------|---------|---------|
| MDs | | | | | |
| Total | 19 (59) | 183.5 | 9.7 | 0.5 | 32 |
| Clinical | | 153.5 | 8.1 | 0.5 | 25 |
| PhDs | | | | | |
| Total | 9 (28) | 86.5 | 9.6 | 2 | 20 |
| Clinical | | 57.5 | 6.4 | 0.5 | 20 |
| FMGs | | | | | |
| Total | 4 (13) | 37.5 | 9.3 | 2.4 | 15 |
| Clinical | | 30.5 | 7.6 | 2.5 | 19 |
| All | | | | | |
| Total | 32 (100) | 307.5 | 9.6 | 0.5 | 32 |
| Clinical | | 241.1 | 7.5 | 0.5 | 25 |

FMG, foreign medical graduate.

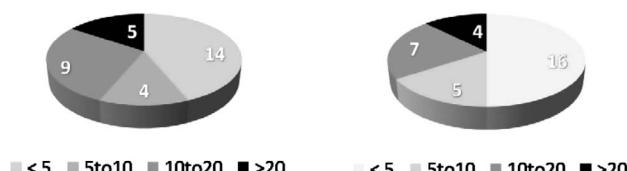
Overall MEG Experience (Years) Clinical MEG Experience (Years)

FIG. 3. Declared Overall and Clinical MEG Experience by Doctoral-level Professional Survey Participants.

The four oldest centers completing the survey were Scripps Clinic in LaJolla, CA (21 years in operation), Henry Ford Hospital in Detroit, MI (20 years), UCSF Hospital in San Francisco, CA (14 years), and UT Houston Hospital in Houston, TX (11 years), which accounted for almost two thirds of the claimed total time in operation. This reflects the fact that the majority of MEG centers were opened more recently between 2000 and 2010 when approximately 20 new MEG systems were installed. Despite the negative effects of unfavorable economics and the closure of some centers, 35 MEG systems (of all types and generations) are operational in the United States currently.

As expected, the most productive centers have a larger dedicated team that included at least one technologist, one or more doctoral-level professionals, and a practicing physician. In addition to expected diversity of organizational structures, there was a larger than expected variability in daily practice.

In 2008, less than 900 epilepsy MEG studies were performed per year (Fig. 1). Thus, only one third of patients undergoing epilepsy surgery (estimated at about 3000 annually) (Engel et al., 2003) benefited from MEG. Increased appropriate clinical use of MEG may provide an important contribution to increasing the use of epilepsy surgery, given that it is the only potential cure for epilepsy. Importantly, increased clinical volumes at less active centers would improve a worrisome underexposure of some junior staff to clinical MEG (Aminoff, 2008; Chernovsky, 1980; Clavien et al., 2005; Lockley et al., 2006; McCray et al., 2008). Our results showed that presurgical functional brain mapping studies (Alberstone et al., 2000; Orrison, 1999) are performed much less often than expected by some neurosurgical institutions that acquired a MEG system as a “mapping tool” (Mäkelä et al., 2006). For both years surveyed, epilepsy studies exceeded presurgical functional brain mapping. Furthermore, in reality, most SEFs are performed to provide a “biological” reference and not for a surgical landmark. Regardless, with more sustained collaborative efforts, MEG-based neuronavigational

TABLE 4. Answers to Question 5 in Appendix 2

| | MD* | Phys† | Neu | Rad | FMG | PhD‡ | All |
|-------|-----|-------|-----|-----|-----|------|-----|
| N | 23 | 19 | 14 | 4 | 4 | 9 | 32 |
| a | 1 | 0 | 0 | 0 | 0 | 1 | 2 |
| b | 13 | 11 | 10 | 0 | 3 | 4 | 18 |
| c | 6 | 5 | 3 | 2 | 1 | 1 | 7 |
| d | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| e | 2 | 2 | 0 | 2 | 0 | 0 | 2 |
| Total | 22 | 18 | 13 | 4 | 4 | 6 | 29§ |

*MDs include all licensed physicians practicing in the United States and foreign medical graduate (FMG) without license.

†Physicians (Phys) include neurologists (Neu), radiologists (Rad), and 1 psychiatrist.

‡PhDs include all PhD, regardless of the field of their doctorate (physics, 4; psychology, 3; neuroscience, 2).

§Three participants (1 physicist, 1 psychologist, and 1 neurologist) decided to provide only a comment.

maps are likely to become a necessity of the “smart operating rooms” of the next decade (Moses and Park, 2009).

The clinically reassuring finding that all centers claimed using EEG in some way simultaneously with MEG (question 9) (Barkley and Baumgartner, 2003; Ebersole and Ebersole, 2010) is dampened significantly by the fact that at least one third of centers use it simply as a quick pointer to the potentially important segments of MEG. However, one fifth of the centers claimed combining source localization of both modalities (MEG and EEG) and providing an integrated MEG–EEG interpretation.

Only the ECD source model was used and accepted by all surveyed centers (Brenner et al., 1975, 1978; Ebersole, 1997; Hari et al., 1988; Williamson et al., 1991) (question 10). Six centers used some other investigational method(s) as well (Schwartz et al., 2008; Xiang et al., 2010). Proprietary software of the MEG vendors (question 11) is one area lagging behind the latest technology. It is a reasonable expectation that those concerned would address this issue expeditiously (Wendel et al., 2009). Highly variable time of reporting (0.5 to 30 days) (question 12), unrelated to the volume of clinical MEG studies (data not shown), likely reflects these differences in study processing.

TABLE 5. Answers to Question 6 in Appendix 2

| | MD* | Phys† | Neu‡ | Rad | FMG | PhD§ | All |
|-------|-----|-------|------|-----|-----|------|-----|
| N | 23 | 19 | 14 | 4 | 4 | 9 | 32 |
| a | 2 | 2 | 2 | 0 | 0 | 2 | 4 |
| b | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| c¶ | 6 | 3 | 3 | 0 | 3 | 6 | 12 |
| d ¶ | 12 | 11 | 6 | 4 | 1 | 2 | 14 |
| e# | 3 | 3 | 3 | 0 | 0 | 0 | 3 |
| f | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| g# | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| Total | 24 | 20 | 15 | 4 | 4 | 10 | 34 |

*MDs include all licensed physicians practicing in the United States and foreign medical graduate (FMG) without license.

†Physicians (Phys) include neurologists (Neu), radiologists (Rad), and 1 psychiatrist.

‡One neurologist provided a comment only.

§PhDs include all PhD, regardless of the field of their doctorate (physics, 4; psychology, 3; neuroscience, 2).

||One neurologist picked answers a and d as their first choice.

¶One physicist picked answers c and d as their first choice.

||One neurologist picked answers e and g as their first choice.

TABLE 3. Answers to Question 4 in Appendix 2

| | MD* | Phys† | Neu | Rad | FMG | PhD‡ | All |
|-------|-----|-------|-----|-----|-----|------|-----|
| N | 23 | 19 | 14 | 4 | 4 | 9 | 32 |
| a | 20 | 16 | 11 | 4 | 4 | 8 | 28 |
| b | 2 | 2 | 2 | 0 | 0 | 1 | 3 |
| c | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| d | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| e | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 22 | 18 | 13 | 4 | 4 | 9 | 31§ |

*MDs include all licensed physicians practicing in the United States and foreign medical graduate (FMG) without license.

†Physicians (Phys) include neurologists (Neu), radiologists (Rad), and 1 psychiatrist.

‡PhDs include all PhD, regardless of the field of their doctorate (physics, 4; psychology, 3; neuroscience, 2).

§One neurologist did not answer but commented.

Although language lateralization (Salmelin, 2007) is the evoked field test least frequently performed, it may become increasingly important given its potential to replace the language lateralization aspect of Wada test (Papanicolaou et al., 2005). Unfortunately, there is no agreement regarding the best way to perform this study (Pirmoradi et al., 2010). Motor mapping shares infrequent utilization and variability in paradigms also exists, such as finger tapping (Pollock et al., 2009) versus hand squeezing (Cramer et al., 2002), which are physiologically quite different. One would expect that a high degree of conformity would exist in the number of responses averaged in mapping a particular modality (American Clinical Neurophysiology Society, 2006; Nakasato and Yoshimoto, 2000). Unfortunately the range stated by our participants was remarkably large—19-fold for language-related brain magnetic fields, 9-fold for movement-related magnetic fields, 5-fold for SEFs and visual evoked fields, and 4-fold for auditory evoked fields. While some variability is due to the difference in paradigms, stimuli, and approaches (Castillo et al., 2004; Pirmoradi et al., 2010; Salmelin, 2007; Schwartz et al., 2008), it still remains puzzling that it is so large.

The participants of MEG Center Doctoral-Level Staff Survey included 23 (72%) MDs and 9 (28%) PhDs (Table 2) (question 3). Neurologists were the single largest group and represented 74% of licensed physicians, 61% of all MDs, and 44% of the entire group. There was no appreciable difference in an average overall experience of our participants regardless of their degree (Table 2) (questions 1 and 2). The majority (87.5%) of participants were aware that in fact, there are no accepted clinical MEG standards (Table 3) (question 4), and those who were not certain were among the more inexperienced. Neurologists (78%) were mostly in favor of defined standards (Table 4) (question 5), while this was a minority view among PhDs (44%) and completely rejected by radiologists (4 of 4). One could speculate that the existence of some kind of presumed “personal” standards may be suggested by one fifth (22%) of participants who thought that “standards would not change what they do.” Admittedly, this survey was not designed to have sensitivity to explain the reasons behind particular views, but one could speculate that those against establishing standards are less aware of the physiological complexity of MEG and/or presume their competency given that MEG is misconceived as a simple imaging technique by some.

Many doctoral professionals believed that “certification would improve the quality of patient care and help propel clinical MEG but should not be mandatory.” One wonders if this implies that improved standards are needed in general, but they should not necessarily be applicable to all centers.

Overall, the majority (81%; Table 5) (question 6) of those surveyed displayed a positive attitude toward certification (Becker et al., 2010; Chernesky, 1980; Clavien et al., 2005) by welcoming an “appropriate form of standardized training *with certification*” (c) or believing that it “would improve the quality of patient care and help propel clinical MEG” (d). A minority of neurologists (6 of 14) and PhDs (2 of 9), but all 4 radiologists, were against mandatory certification (d). Conversely, the majority of nonphysicians (6 of 9) and foreign medical graduates (3/4) favored “standardized training *with certification*.” Such a certification is likely perceived by them as a formalized route for achieving the professional acceptance that they deserve.

Standards of practice in the form of Clinical Practice Guidelines have been a reality for the medical profession for decades (Schorow and Carpenter, 1971; Talley, 1990), and the field of neurology is not an exception (Wiebe, 2010). However, the implementation of practice standards has varied (Haneef et al., 2010; Wiebe,

2010) despite expert consensus (Engel et al., 2003) after randomized controlled trials (Wiebe et al., 2001). One may ask to what degree guidelines in fact change the behavior of clinicians (Haneef et al., 2010; Wiebe, 2010). There seems to be an emerging belief that a direct interaction between clinical experts and practitioners provides the best influence on subsequent implementation of guidelines (Akbari et al., 2008). Considering that clinical MEG is still in its formative years, this presents a great opportunity.

CONCLUDING REMARKS

We are entering a new phase in the evolution of clinical MEG. Its diagnostic usefulness has been confirmed, and it is becoming increasingly accepted, even by most commercial insurers, as a routine clinical practice. As such, the present marks a time when establishing MEG guidelines is necessary for fulfilling our professional role in delivering optimal and consistent patient care (Nahrwold, 2010). Having confirmed the current diversity of clinical MEG practice by means of this survey, American Clinical Magnetoencephalography Society is even more dedicated to develop the first clinical practice guidelines for MEG.

Appendix 1

MEG Center Director(s) Survey

(Please read all choices before selecting your answer for a given question)

1. When was your MEG center established?
 2. How many staff members (full time equivalents - FTEs) do you have working in your center DIRECTLY and what is their educational profile and expertise?
 - A. Licensed Physician (specify your specialty): Neurology, Epilepsy, Neurophysiology, Radiology, Neurosurgery, Other, None
 - B. Foreign Medical Graduate (FMG) WITHOUT license
 - C. Non-physician (specify a field of Ph.D.): Psychology, Neuroscience, Physics, Biology, Other
 - D. Technicians, E. Nurse, F. Others
 3. Training and experience of person(s) that RUN your facility
 - A. Licensed Physician (specify your specialty): Neurology, Epilepsy, Neurophysiology, Radiology, Neurosurgery, Other, None
 - B. Foreign Medical Graduate (FMG) WITHOUT license
 - C. Non-physician (specify a field of Ph.D.): Psychology, Neuroscience, Physics, Biology, Other
 4. Training and experience of person(s) who READ respective CLINICAL studies?
 - A. Licensed Physician (specify your specialty): Neurology, Epilepsy, Neurophysiology, Radiology, Neurosurgery, Other, None
 - B. Foreign Medical Graduate (FMG) WITHOUT license
 - C. Non-physician (specify a field of Ph.D.): Psychology, Neuroscience, Physics, Biology, Other
 5. Training and experience of person(s) who SIGN respective CLINICAL studies:
 - A. Licensed Physician (specify your specialty): Neurology, Epilepsy, Neurophysiology, Radiology, Neurosurgery, Other, None
 - B. Foreign Medical Graduate (FMG) WITHOUT license
 - C. Non-physician (specify a field of Ph.D.): Psychology, Neuroscience, Physics, Biology, Other

6. Annual number of CLINICALLY indicated and billed epilepsy localization studies in 2006 and 2007.
7. Annual number of CLINICALLY indicated and billed pre-surgical MEG mappings counting each modality individually (AEF = Auditory Evoked Magnetic Fields, LRF = Language-Related Brain Magnetic Fields, MRF = Movement-Related Magnetic Fields, SEF = Somatosensory Evoked Magnetic Fields, VEF = Visual Evoked Magnetic Fields) in 2006 and 2007.
8. Annual number of RESEARCH MEG studies in 2006 and 2007.
9. While READING a clinical epilepsy MEG study, how does your center use an EEG?
- Do not use EEG
 - Identify spikes in EEG and then perform dipole fitting of corresponding MEG spikes
 - Review MEG independently, dipole fit MEG EDs, review EEG independently for spikes and fit their MEG correlates, then interpret together in the context of clinical picture
 - Review MEG independently, dipole fit MEG epileptiform discharges (EDs), review EEG for spikes and fit EEG spikes using appropriate head model, then interpret together in the context of clinical picture
10. What source modeling methods do you use ROUTINELY in clinical practice?
- Use only equivalent current dipole (ECD)
 - Combine ECD with beamformers
 - Combine CD with other methods but NOT beamformers
 - Combine ECD, beamformers, AND other methods
11. What software do you use IN CLINICAL PRACTICE?
- Proprietary software of a MEG vendor ONLY
 - Commercial software ONLY
 - Proprietary and commercial software
12. Within how many days do you report CLINICAL studies? Epilepsy ____ days Mapping ____ days
13. When mapping language function(s), what paradigms do you use?
- Silent naming
 - Silent reading
 - Dichotic listening
 - Other
 - None
14. When mapping motor function(s), what paradigms do you use?
- Finger tapping
 - Finger flexion-extension
 - Hand squeezing and relaxing
 - Other
 - None
15. How long do you usually run MEG recording for epilepsy localization?
- <30 minutes
 - 30 minutes
 - 30-60 minutes
 - >60 minutes
 - e) Depends on number of spikes identified during acquisition
16. How many accepted average responses do you usually seek for each modality being mapped?
- A. Auditory Evoked Magnetic Fields (AEF)
B. Language-Related Brain Magnetic Fields (LRF)
C. Movement-Related Magnetic Fields (MRF)
D. Somatosensory Evoked Magnetic Fields (SEF)
E. Visual Evoked Magnetic Fields (VEF)
17. How would you define your implementation of “clinical MEG standards”?
- There are no accepted clinical MEG standards
 - I am not sure if clinical MEG standards exist
 - Clinical MEG standards exist but I am not familiar with them
 - I am very familiar with standards and strictly adhere
 - I know what I am doing and need no standards
18. How would you define your attitude towards establishing clinical MEG standards?
- Everybody in the field knows the standards
 - We need accepted standards as soon as possible
 - Standards would not change what we do
 - I know what I am doing and need no standards
 - I don’t care
19. Please select statement(s) that best reflect your attitude towards formalized certification for reading clinical MEG studies? If you select multiple statements, please rank them in order of importance.
- I would welcome appropriate form of standardized training WITHOUT certification
 - I would welcome appropriate form of certification WITHOUT required standardized training
 - I would welcome appropriate form of standardized training WITH certification
 - Certification would improve quality of patient care and help propelling clinical MEG, but should not be mandatory
 - I oppose certification since it is just unnecessary intricacy of medical profession
 - Certification would only antagonize those used to it (i.e. physicians) and those who are not (i.e. non-physicians)g) Certification is a formality that would have no practical effect on the MEG field
20. How much time did you need to fill this survey? ____ min.

Appendix 2

MEG Center Doctoral-Level Staff Survey

(Please read all choices before selecting your answer for a given question)

- How many years of experience in MEG do you have?
- How many years of experience in CLINICAL MEG do you have?
- What is the best description of your training and expertise?
 - Licensed Physician (specify your specialty): Neurology, Epilepsy, Neurophysiology, Radiology, Neurosurgery, Other, None
 - Foreign Medical Graduate (FMG) WITHOUT license
 - Non-physician (specify a field of Ph.D.): Psychology, Neuroscience, Physics, Biology, Other.
- How would you define your implementation of “clinical MEG standards”?
 - There are no accepted clinical MEG standards

- B. I am not sure if clinical MEG standards exist
 - C. Clinical MEG standards exist but I am not familiar with them
 - D. I am very familiar with standards and strictly adhere
 - E. I know what I am doing and need no standards
5. How would you define your attitude towards establishing clinical MEG standards?
- A. Everybody in the field knows the standards
 - B. We need accepted standards as soon as possible
 - C. Standards would not change what we do
 - D. I know what I am doing and need no standards
 - E. I don't care
6. Please select statement(s) that best reflect your attitude towards formalized certification for reading clinical MEG studies? If you select multiple statements, please rank them in order of importance.
- A. I would welcome appropriate form of standardized training WITHOUT certification
 - B. I would welcome appropriate form of certification WITHOUT required standardized training
 - C. I would welcome appropriate form of standardized training WITH certification
 - D. Certification would improve quality of patient care and help propel clinical MEG, but should not be mandatory
 - E. I oppose certification since it is just an unnecessary intricacy of the medical profession
 - F. Certification would only antagonize those who are used to it (i.e. physicians) and those who are not (i.e. non-physicians)
 - G. Certification is a formality that would have no practical effect on the MEG field.

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