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

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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.

(*J Clin Neurophysiol* 2011;28: 341–347)

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 (Bagic et al., 2009). The time is rife 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 (Bagic 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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ISSN: 1070-8022/11/2804-0341

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).

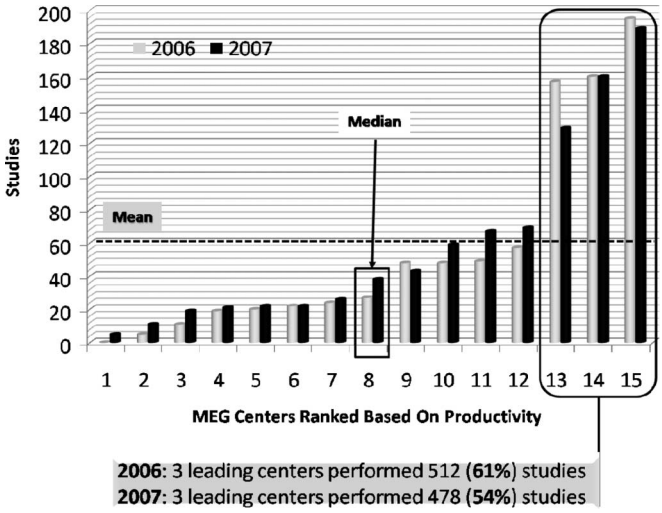

FIG. 1. Clinical epilepsy MEG studies performed by each participating USA center in 2006 and 2007.

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 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.

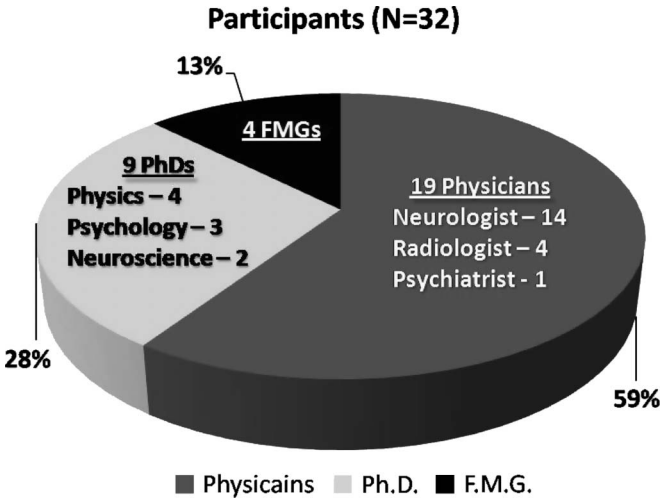

FIG. 2. Educational Profile of Doctoral-level Professional Survey Participants.

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.

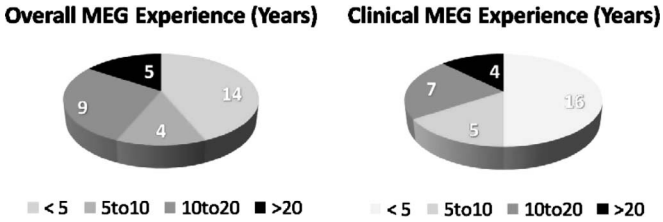

FIG. 3. Declared Overall and Clinical MEG Experience by Doctoral-level Professional Survey Participants.

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 third 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 doctorial-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; Chernesky, 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 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 methods(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 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.

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.

TABLE 5. Answers to Question 6 in Appendix 2

N	MD* 23	Phys† 19	Neu‡ 14	Rad 4	FMG 4	PhD§ 9	All 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.

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 (Pollok 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?
   A. Do not use EEG
   B. Identify spikes in EEG and then perform dipole fitting of corresponding MEG spikes
   C. 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
   D. 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?
    A. Use only equivalent current dipole (ECD)
    B. Combine ECD with beamformers
    C. Combine CD with other methods but NOT beamformers
    D. Combine ECD, beamformers, AND other methods

11. What software do you use IN CLINICAL PRACTICE?
    A. Proprietary software of a MEG vendor ONLY
    B. Commercial software ONLY
    C. 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?
    A. Silent naming
    B. Silent reading
    C. Dichotic listening
    D. Other
    E. None

14. When mapping motor function(s), what paradigms do you use?
    A. Finger tapping
    B. Finger flexion-extension
    C. Hand squeezing and relaxing
    D. Other
    E. None

15. How long do you usually run MEG recording for epilepsy localization?
    A. <30 minutes
    B. 30 minutes
    C. 30-60 minutes
    D. >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"?
    A. 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

18. 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

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.
    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 propelling clinical MEG, but should not be mandatory
    E. I oppose certification since it is just unnecessary intricacy of medical profession
    F. 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)

1. How many years of experience in MEG do you have?

2. How many years of experience in CLINICAL MEG do you have?

3. What is the best description of your training 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.

4. How would you define your implementation of "clinical MEG standards"?
   A. 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.

REFERENCES

Akbari A, Mayhew A, Al-Alawi MA, et al. Interventions to improve outpatient referrals from primary care to secondary care. *Cochrane Database Syst Rev* October 2008;4:CD005471.

Alberstone CD, Skirboll SL, Benzel EC, et al. Magnetic source imaging and brain surgery: presurgical and intraoperative planning in 26 patients. *J Neurosurg* 2000;92:79–90.

American Clinical Neurophysiology Society (ACNS). Guideline 9A: Guidelines on evoked potentials. Available at: http://www.acns.org/guidelines.cfm. Accessed April 15, 2011.

Aminoff MJ. Training in neurology. *Neurology* 2008;70:1912–1915.

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.

Barkley GL, Baumgartner C. MEG and EEG in epilepsy. *J Clin Neurophysiol* 2003;20:163–178.

Becker GJ, Dunnick NR, Bosma JL. The future of board certification. *J Am Coll Radiol* 2010;7:338.

Brenner D, Williamson SJ, Kaufman L. Visually evoked magnetic fields of the human brain. *Science* 1975;190:480–482.

Brenner D, Lipton J, Kaufman L, Williamson SJ. Somatically evoked magnetic fields of the human brain. *Science* 1978;199:81–83.

Castillo EM, Simos PG, Wheless JW, et al. Integrating sensory and motor mapping in a comprehensive MEG protocol: clinical validity and replicability. *Neuroimage* 2004;21:973–983.

Chernesky RH. Establishing an accountability system: an experience involving professional staff review. *Adm Soc Work* 1980;4:75–81.

Clavien PA, Nahrwold DL, Soper NJ, Bass BL. Physician competency? Teaching old dogs new tricks. *J Gastrointest Surg* 2005;9:625–632.

Cohen D. Magnetoencephalography: evidence of magnetic fields produced by alpha-rhythm currents. *Science* 1968;161:784–786.

Cohen D. Magnetoencephalography: detection of the brain's electrical activity with a superconducting magnetometer. *Science* 1972;175:664–666.

Cramer SC, Weisskoff RM, Schaechter JD, et al. Motor cortex activation is related to force of squeezing. *Hum Brain Mapp* 2002;16:197–205.

Ducassou D, Brendel A, Lacroix F, Brothier JP. Clinical value of single photon emission computerized tomography in encephalic exploration. *Int J Nucl Med Biol* 1980;7:25–31.

Ebersole JS. Magnetoencephalography/magnetic source imaging in the assessment of patients with epilepsy. *Epilepsia* 1997;38:S1–S5.

Ebersole JS, Ebersole SM. Combining MEG and EEG source modeling in epilepsy evaluations. *J Clin Neurophysiol* 2010;27:360–371.

Engel J Jr, Wiebe S, French J, et al. Quality Standards Subcommittee of the American Academy of Neurology; American Epilepsy Society; American Association of Neurological Surgeons. Practice parameter: temporal lobe and localized neocortical resections for epilepsy: report of the Quality Standards Subcommittee of the American Academy of Neurology, in Association with the American Epilepsy Society and the American Association of Neurological Surgeons. *Neurology* 2003;60:538–547.

Funke M, Constantino T, Van Orman C, Rodin E. Magnetoencephalography and magnetic source imaging in epilepsy. *Clin EEG Neurosci* 2009;40:271–280.

Haneef Z, Stern J, Dewar S, Engel J Jr. Referral pattern for epilepsy surgery after evidence-based recommendations: a retrospective study. *Neurology* 2010;75:699–704.

Hari R, Joutsiniemi SL, Sarvas J. Spatial resolution of neuromagnetic records: theoretical calculations in a spherical model. *Electroencephalogr Clin Neurophysiol* 1988;71:64–72.

Knowlton RC, Elgavish RA, Limdi N, et al. Functional imaging: I. Relative predictive value of intracranial electroencephalography. *Ann Neurol* 2008a;64:25–34.

Knowlton RC, Elgavish RA, Bartolucci A, et al. Functional imaging: II. Prediction of epilepsy surgery outcome. *Ann Neurol* 2008b;64:35–41.

Knowlton RC, Razdan SN, Limdi N, et al. Effect of epilepsy magnetic source imaging on intracranial electrode placement. *Ann Neurol* 2009;65:716–723.

Lenzi GL, Jones T, Frackowiak RS. Positron emission tomography: state of the art in neurology. *Prog Nucl Med* 1981;7:118–137.

Lockley SW, Landrigan CP, Barger LK, Czeisler CA. Harvard Work Hours Health and Safety Group. When policy meets physiology: the challenge of reducing resident work hours. *Clin Orthop Relat Res* 2006;449:116–127.

Mäkelä JP, Forss N, Jääskeläinen J, et al. Magnetoencephalography in neurosurgery. *Neurosurgery* 2006;59:493–510discussion 510–511.

McCray LW, Cronholm PF, Bogner HR, et al. Resident physician burnout: is there hope? *Fam Med* 2008;40:626–632.

Moses GR, Park AE. A research portfolio for innovation in the surgical environment. *Stud Health Technol Inform* 2009;142:189–194.

Nahrwold DL. Presentation in honor of the 75th anniversary of the ABR: the future of board certification. *J Am Coll Radiol* 2010;7:334–337.

Nakasato N, Yoshimoto T. Somatosensory, auditory, and visual evoked magnetic fields in patients with brain diseases. *J Clin Neurophysiol* 2000;17:201–211.

Ogawa S, Lee TM, Kay AR, Tank DW. Brain magnetic resonance imaging with contrast dependent on blood oxygenation. *Proc Natl Acad Sci U S A* 1990;87:9868–9872.

Orrison WW Jr. Magnetic source imaging in stereotactic and functional neurosurgery. *Stereotact Funct Neurosurg* 1999;72:89–94.

Papanicolaou AC, Pataraia E, Billingsley-Marshall R, et al. Toward the substitution of invasive electroencephalography in epilepsy surgery. *J Clin Neurophysiol* 2005;22:231–237.

Pirmoradi M, Béland R, Nguyen DK, et al. Language tasks used for the presurgical assessment of epileptic patients with MEG. *Epileptic Disord* 2010;12:97–108.

Pollok B, Krause V, Butz M, Schnitzler A. Modality specific functional interaction in sensorimotor synchronization. *Hum Brain Mapp* 2009;30:1783–1790.

Salmelin R. Clinical neurophysiology of language: the MEG approach. *Clin Neurophysiol* 2007;118:237–254.

Schorow M, Carpenter D. Participant-directed continuing education workshop developed guidelines for coronary care units. *Hosp Manage* 1971;111:28.

Schwartz ES, Dlugos DJ, Storm PB, et al. Magnetoencephalography for pediatric epilepsy: how we do it. *AJNR Am J Neuroradiol* 2008;29:832–837.

Sutherling WW, Mamelak AN, Thyerlei D, et al. Influence of magnetic source imaging for planning intracranial EEG in epilepsy. *Neurology* 2008;71:990–996.

Wendel K, Väisänen O, Malmivuo J, et al. EEG/MEG source imaging: methods, challenges, and open issues [published online ahead of print July 20, 2009]. *Comput Intell Neurosci* 2009;656092.

Wiebe S. Still an elusive target: guiding practice for epilepsy surgery. *Neurology* 2010;75:678–679.

Wiebe S, Blume WT, Girvin JP, Eliasziw M. Effectiveness and Efficiency of Surgery for Temporal Lobe Epilepsy Study Group. A randomized, controlled trial of surgery for temporal-lobe epilepsy. *N Engl J Med* 2001;345:311–318.

Williamson SJ, Lü ZL, Karron D, Kaufman L. Advantages and limitations of magnetic source imaging. *Brain Topogr* 1991;4:169–180.

Xiang J, Wang Y, Chen Y, et al. Noninvasive localization of epileptogenic zones with ictal high-frequency neuromagnetic signals. *J Neurosurg Pediatr* 2010;5:113–122.

