Benefit of Simultaneous Recording of EEG and MEG in Dipole Localization

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Summary: Purpose: In this study, we tried to show that EEG and magnetoencephalography (MEG) are clinically complementary to each other and that a combination of both technologies is useful for the precise diagnosis of epileptic focus.

Methods: We recorded EEGs and MEGs simultaneously and analyzed dipoles in seven patients with intractable localization-related epilepsy. MEG dipoles were analyzed by using a BTI Magnes 148-channel magnetometer. EEG dipoles were analyzed by using a realistically shaped four-layered head model (scalp–skull–fluid–brain) built from 2.0-mm slice magnetic resonance imaging (MRI) images.

Results: (a) In two of seven patients, MEG could not detect any epileptiform discharges, whereas EEG showed clear spikes. However, dipoles estimated from the MEG data corresponding to the early phase of EEG spikes clustered at a location close to that of the EEG-detected dipole. (b) In two of seven patients, EEG showed only intermittent high-voltage slow waves (HVSs) without definite spikes. However, MEG showed clear epileptiform discharges preceding these EEG-detected HVSs. Dipoles estimated for these EEG-detected HVSs were located at a location close to that of the MEG-detected dipoles. (c) Based on the agreement of the results of these two techniques, surgical resection was performed in one patient with good results.

Conclusions: Dipole modeling of epileptiform activity by MEG and EEG sometimes provides information not obtainable with either modality used alone. Key Words: MEG—EEG—Localization-related epilepsy—Dipole.

The dipole localization method has been widely used for noninvasive localization of spike foci (1–3). After the development of magnetoencephalography (MEG), most comparative studies of MEG and EEG have focused on comparing the localization accuracy of MEG and EEG dipoles (4,5). We addressed the way in which dipole localization with a combination of MEG and EEG supplements the information obtainable by either technique alone. We try to show that EEG and MEG are clinically complementary to each other, and that a combination of both technologies is useful for the precise diagnosis of epilepsy patients.

PATIENTS AND METHODS

Subjects were drawn from all the outpatients and inpatients of Okayama University Hospital who were being considered for antiepileptic surgery between July 2000 and June 2001. We obtained consent from the parents of seven of these patients to perform MEG investigation at the Okayama Ryogo Center. The patients consisted of six boys and one girl (average age, 15 years and 1 month; range, 5 years and 7 months to 19 years and 2 months). All the patients had intractable localization-related epilepsy.

We recorded EEGs and MEGs simultaneously. MEGs were recorded with a 148-channel whole-head magnetometer (BTI Magnes, San Diego, CA, U.S.A.) with simultaneous 21-channel EEG recording by using the international 10-20 system with additional electrodes at Fpz and Oz referenced to the ears. The MEG and EEG sampling rates were 678.17 and 500 Hz. The MEG signal was filtered in real time with a highpass of 200 Hz and a lowpass of 0.1 Hz. EEG was filtered with 0.5–100 Hz. Common reference points (nasion, inion, and ear holes) were used for MEG, EEG, and magnetic resonance imaging (MRI) for coregistration of the data.

Both EEG and MEG outputs were monitored on real-time displays. The data epochs were visually selected by using both the MEG and EEG waveforms. We marked...
0.5- to 1-s segments that contained epileptiform spikes and were free of artifact and selected 10 to 20 of these segments to be analyzed.

MEG dipoles were calculated based on data from 37 channels selected over the region of interest. MEG dipoles were analyzed by the single-dipole model with the BTI program. In the calculations, the head was modeled as a sphere with a radius that best fit the local skull curvature at the probe positions. The skull shape was derived from a three-dimensional (3D) digitalization of the surface of the patient’s scalp before the recording session.

According to the Homma’s dipole theory (6), EEG dipoles were analyzed by using a realistically shaped four-layered head model (scalp–skull–fluid–brain) built from 2.0-mm slice MRI images (Real-Neurotechnology Co., Toyama, Japan). Both MEG and EEG dipoles were estimated every 2 ms, and the locations of dipoles exhibiting >0.98 correlation were displayed. The MEG dipole localizations were coregistered with MRI (1.5 Tesla, GE Co.) of the patient’s brain automatically. We compared the EEG dipole localizations on MRI by visual inspection. When either EEG or MEG could not detect any clear epileptic discharges, the dipole analyses were performed at the corresponding points to the epileptic discharges found with the other technique. That is to say, EEG spikes were used to determine the MEG epoch for analyzing in cases without MEG spikes and vice versa.

We received consent to perform surgery on one of the patients mentioned in this series (case 3, described later).

RESULTS

In two of the seven patients, EEG showed clear spikes where MEG could not detect any clear epileptiform discharges. The following is an example of such a case.

Case 1

An 18-year-old man had complex partial seizures with visual symptoms. His EEG showed focal spikes at the right occipital electrode. MEG could not detect a dipolar field at a single section corresponding to the early phase of the EEG spikes. Therefore, averaging techniques were applied to 38 MEG segments, by using EEG spikes as markers, and this produced a clear dipolar field on averaged MEGs. Dipoles estimated for this dipolar field were located in the mesial occipital lobe, which corresponded well with his clinical features (Fig. 1).

In another case, dipoles estimated from the MEG data corresponding to the early phase of the EEG spikes clustered at a location close to that of the EEG dipole (both dipoles were located in the right mesial temporal lobe). These results corresponded well with his clinical and neuroimaging data.

In two of the seven patients, EEG showed only intermittent high-voltage slow waves (HVSs) without definite spikes. MEG showed clear spikes preceding these EEG-detected HVSs. Dipoles estimated for the ascending phase of these EEG-detected HVSs were located close to the dipoles estimated by MEG. The following case is representative of these two cases.

Case 2

A 16-year-old boy had complex partial seizures with motor signs predominantly in his left arm, and secondarily generalized seizures. Interictal single-photon emission computed tomography (SPECT) revealed a hypoperfusion area in both his frontal and temporal lobes, whereas MRI revealed no abnormal lesions. His EEG showed bilateral HVS bursts in the frontal area. MEG showed clear epileptiform discharges preceding these EEG-detected HVS bursts. EEG dipoles estimated for the peak of these HVS bursts were located at the bottom of the frontal lobe, far from the MEG-estimated dipole locations. However, dipoles estimated for the ascending phase of these EEG-detected HVS bursts were located close to the location of the MEG-estimated dipoles (in the same or the neighboring gyri as the MEG-estimated dipoles; Fig. 2).

Three patients showed clear epileptic spikes on both EEG and MEG. In these cases, EEG and MEG dipoles corresponded well to each other. The following is an example of such a case.

Case 3

A 19-year-old man had complex partial seizures with vocalization followed by ballistic movement of his arms and legs. Ictal SPECT revealed a hyperperfusion area in the bottom of the left mesial frontal lobe, and MRI revealed cortical dysplasia in that area. Both EEG and MEG showed clear epileptic spikes in the bilateral frontal lobes. EEG also showed bilateral HVS bursts in the frontal area. MEG showed clear epileptiform discharges preceding these EEG-detected HVS bursts. Both dipoles estimated for the ascending phase of these EEG-detected HVS bursts and EEG epileptic spikes were located in the bottom of the left frontal mesial lobe, close to the location of the MEG-estimated dipoles (Fig. 3). Conversely, dipole analysis also was performed for other high-voltage discharges observed on MEG but not accompanied by EEG discharges. The resulting dipoles were located far from the epileptogenic area indicated by the other imaging techniques. In this case, EEG would not have accurately detected the dipole location without the information provided by MEG, and MEG would not have accurately detected the dipole location without the information provided by EEG. Thus, in this case, EEG and MEG played complementary roles in dipole analysis. Based on further data obtained by subdural and deep electrodes, surgery was performed on the patient’s left
mesial frontal area at Nara Medical University. At the time of writing, the patient has been seizure free for 6 months.

**DISCUSSION**

When it was first introduced, EEG dipole analysis held great promise as a noninvasive method for presurgical epilepsy evaluation (1–3). However, EEG has now been overshadowed by the newer MEG technology. One reason for this is that MEG has better localization accuracy than EEG, because the signal is not distorted by concentric heterogeneities in conductivity.

The complementary nature of MEG and EEG has been described in the past 10 years (7–10). The authors of these articles pointed out that these techniques are complementary for the following reasons: (a) EEG reflects all intracranial currents, whereas MEG is sensitive mainly to tangential sources (i.e., activity of the fissural cortex); and (b) the magnetic field from sources near the center of the head falls off more quickly than the corresponding electric field; as a consequence, MEG is less sensitive to deep sources than is EEG.

In two of our seven cases, MEG could not detect any clear epileptiform discharges, whereas EEG showed clear spikes. In these cases, EEG spikes were useful for determining which MEG epoch to analyze. In case 1, the averaging procedure reduced background noise and produced the dipolar field in MEG. It would have been impossible to know which sections to analyze and average without the EEG information.

In contrast, in another two of our seven cases, EEG showed only intermittent high-voltage slow waves (HVSs) without definite spikes, whereas MEG showed clear spikes preceding these EEG-detected HVSs. Dipoles estimated for the ascending phase of these EEG-detected HVSs were located at a location close to that of the MEG dipoles.

Nakasato et al. (11) found that EEG sometimes inaccurately detected dipoles in an area deep in the base of the skull, significantly displaced from where MEG indi-

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**FIG. 1.** EEG spike in the right occipital area (arrow, lower left). In the middle of the figure is the averaged magnetoencephalogram (MEG), which was produced by averaging 38 segments of the MEG. This yielded an apparent spike. Upper right, the topography of the averaged MEG. Lower right, the MEG dipole.
cated these lesions to be. The reason for this disparity could be the wide spread of the radial EEG pattern, where one polarity covers the entire upper hemisphere in the spherical EEG model. In our cases, the HVS peaks might have been the result of widespread electrical activity. Thus the EEG dipoles at the peaks of the HVSs were located at the bottom of the frontal lobe.

Some authors found that MEG peaks preceded the main EEG peak by 9–40 ms in some patients (12,13). Therefore they emphasized the importance of modeling the early phases of EEG spikes when localizing interictal epileptic zones. Epileptic spikes commonly propagate, and both magnetic and electric fields change over the course of the spike. Minami et al. (13) explained this propagation based on findings that MEG and EEG spikes propagate in a similar manner to somatosensory-evoked magnetic field (SEF). Ochi et al. (10) also showed how differences between the orientation of EEG and MEG dipoles could explain time differences between the two dipoles. Because magnetic fields can lead or lag EEG fields, depending on the orientation of the initial source cortex and that of the cortex to which the spike propagates, it is important to model the early fields, which more closely reflect the actual spike origin.

In our case 2, the epileptogenic focus would have been incorrectly estimated if dipole analyses were performed only at the peak of these HVSs without the information provided by MEG. In addition, we sometimes encountered patients who showed no definite epileptic spikes but only paroxysmal HVSs on EEGs. The results indicated by EEG dipoles of these HVSs, which corresponded well to MEG spike dipoles, suggest that these HVSs point to the true location of the epileptogenic zone.

**Conclusion**

In at least five of our cases, the combination of MEG and EEG dipole analysis provided information that would not have been obtained by use of either modality individually. In one case, combined use led to successful localization for surgery.
REFERENCES


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