My Dreams of MEG in the Late 1980s and in the Present

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Abstract Here, I review my MEG research history of from a single-channel magnetoencephalography (MEG) system using superconducting quantum interference device (SQUID) in the late 1980s to another single-channel MEG era using tunnel magnetic resistance (TMR) sensors. MEG contributed clinically a lot not only because of its higher spatial resolution than electroencephalography (EEG), but also the fact that MEG opened a door into source-based interpretation of EEG interpretation rather than traditional sensor-based EEG reading.

1. The single-channelers in the late 1980's

Here is a photo of single-channel MEG researchers in 1980's (Fig. 1). We used to place a single channel-SQUID probe one site to another to map a dipole pattern over subject's scalp, taking weeks or even months [1]. We, both engineers and clinicians, had a common dream that one day we would be able to use helmet-shaped multichannel MEG systems for clinical environment. Our dream finally came true in 1990's.

Fig.1 "The Club Single-Channel" at the 6th Meeting of International Society for the Advancement of Clinical MEG, May 22-24, 2017, Sendai, Japan

2. Why MEG in addition to electroencephalography (EEG)?

Among noninvasive imaging tools of human brain function, only EEG and MEG have temporal resolution of millisecond-order. In addition, MEG has theoretically better spatial resolution than EEG. Since development of SQUID in 1970s, MEG has become one of essential methods to localize focal epilepsy and eloquent brain cortices before surgery.

Before popularization of MEG, clinicians paid very little attention to the electric source imaging (ESI). Stimulated by a huge amount of MEG's accomplishment in magnetically source imaging (MSI), ESI have been introducing numerous parameters into the mathematical models. ESI revolutionized old-fashioned visual interpretation of EEG such as in localization of interictal epileptic discharges [2]. Yet EEG and MEG are complimentary each other. Combination of both would be ideal for clinical decision making, especially in epilepsy surgery.

3. Equivalent current dipole (ECD) models

ECD model is the simplest algorithm to localize MEG source. However, it brought a strong impact on brain research and clinical decision making. Helmet MEG systems in my laboratory enabled simple separation of left and right hemispheric sources in both normal [3] and abnormal [4] signals with ECD models.

If measured MEG activity can be explained by a single focal source, accuracy of ECD localization is excellent. For example, we were able to map hand digit sensory areas across a 16 mm span in the posterior wall of the central sulcus [5].

Not only source localization, but also source orientation analysis brings important information for clinical decision making. When epileptic spikes are estimated right on the major sulci facing two cortical surfaces, for examples, orientation of spike ECD may predict epileptogenic side across the sulci [6].

Source amplitude can also be used clinically. Amplitude has usually been analyzed by sensor-sensor voltage in EEG. We applied an ECD model to analyzed N20m, the first component of the median nerve evoked somatosensory responses in MEG. Since primary somatosensory cortex is on the posterior bank of the central sulcus, N20m is known to almost parallel to the scalp surface. Thus MEG-based ECD moment analysis directly provides qualitative evaluation of the function [7]. We found awake state-specific suppression of N20m amplitude was correlated with disease duration of temporal lobe epilepsy.

4. Room temperature MEG

Recently, we have developed TMR sensors for room-temperature MEG [7]. TMR sensors can measure MEG without unnecessary setback distance from the scalp, promising higher spatial resolution than SQUID-MEG. Moreover, dynamic range of TMR is far wider than SQUID. Therefore, in the near future, we will be able to measure MEG outside the shielded room. Smaller size of TMR than SQUID will enable higher density spatial arrangement of multiple sensors. Finally, the cheaper fabrication and running costs of TMR than SQUID will enhance the mass manufacture of MEG and other biomagnetic imaging systems.

I now have a dream today that one day we will be able to monitor human brain activity outside a magnetically shielded room even without a hard helmet. International and multi-disciplinary collaboration of both engineers and clinical researchers will be important toward realization of this dream, again.

References

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