Fundamentals of MagnetoEncephaloGraphy

HyeonMi Park, M.D.
Dept. of Neurology, Gachon University Gil Hospital
Topic

• General principle of MEG
• Comparison: EEG and MEG
• Clinical application of MEG
• Early 19th C, Hans Christian Oersted: electrical currents generate magnetic fields with right-hand rule
Biomagnetic fields directly reflect electrophysiologic events of the brain can pass through the tissues of the body without distortion
1963, Baule and McFee: record biomagnetic data in human heart

Detection of non-ST-elevation myocardial infarction using magnetocardiogram: New information from spatiotemporal electrical activation map

Lim HK, Kim K, Lee YH, Chung N
Korea Research Institute of Standards and Science, Daejeon, Korea
- 1967, Cohen: measure brain's alpha rhythm with Magnetic shielded room

![Graph showing brain waves with eyes closed and open]
I : electric current
B : magnetic field
Magnetic field Strength

<table>
<thead>
<tr>
<th>Magnetic Flux Density *</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10^{15})</td>
<td>Magenetic resonance scanners</td>
</tr>
<tr>
<td>(10^{10})</td>
<td>Earth’s steady magnetic field</td>
</tr>
<tr>
<td>(10^9)</td>
<td></td>
</tr>
<tr>
<td>(10^8)</td>
<td>Urban noise</td>
</tr>
<tr>
<td>(10^7)</td>
<td></td>
</tr>
<tr>
<td>(10^6)</td>
<td>Magnetized lung contaminants</td>
</tr>
<tr>
<td>(10^5)</td>
<td>Gastrointestinal currents</td>
</tr>
<tr>
<td>(10^4)</td>
<td>Magnetocardiogram and oculogram</td>
</tr>
<tr>
<td>(10^3)</td>
<td>Epileptic spikes, magnetic rhythm</td>
</tr>
<tr>
<td>(10^2)</td>
<td>Cortical evoked responses</td>
</tr>
<tr>
<td>(10)</td>
<td>SQUID noise</td>
</tr>
<tr>
<td>1</td>
<td>Brainstem-evoked activity</td>
</tr>
</tbody>
</table>
SQUID; superconducting quantum interference device
FIG. 26. Various types of flux transformers: (a) magnetometer; (b) series planar gradiometer; (c) parallel planar gradiometer; (d) symmetric series axial gradiometer; (e) asymmetric series axial gradiometer; (f) symmetric parallel axial gradiometer; and (g) second-order series axial gradiometer.
<table>
<thead>
<tr>
<th>Type</th>
<th>magnetometer</th>
<th>gradiometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. shape</td>
<td>one coil</td>
<td>two loop</td>
</tr>
<tr>
<td>2. magnetic flux detect</td>
<td>direct</td>
<td>spatial gradient</td>
</tr>
<tr>
<td>3. sensitivity</td>
<td>more wide spread</td>
<td>focal</td>
</tr>
<tr>
<td>4. good</td>
<td>deep source</td>
<td>noise</td>
</tr>
</tbody>
</table>
MEG provides ~

- real-time, direct assessment of brain electrophysiology
- good spatial resolution

• Noninvasive neuroimaging technique with best balance of temporal and spatial sensitivity to brain physiology
Type of Activity

- Spontaneous Brain Activity
- Event related Activity
M20 Somatosensory Response

Time

Right Anterior
a. Somatosensory evoked magnetic signals
b. The isofield contour map
c. The spatial location, orientation, and strength of the neuronal currents
Magnetic Evoked Responses
- Primary Eloquent Area -
Magnetic Source Imaging (MSI)

- Information on brain electrophysiology (by MEG)
- Information on brain anatomy (by MRI)
Comparison of EEG and MEG

- Structure
  - MRI, CT

- Hemodynamic/Metabolism
  - SPECT, PET

- Physiology
  - EEG, MEG
Comparability:

- Anatomy (MRI/CT): comparable / comparable
- Metabolism (PET): much greater / much greater
- Electrophysiology (EEG/ECoG): less / more

Repeatability:
- Preg. Woman, Child
- Repeat

Time resolution differences:
- Spont. Activity
- Time resolution

Disadvantages:
- Invasive technique
- General anesthesia
- Distortion by conductivity

Cost of equipment / procedure
1. noninvasive technique
2. brain conductivity – “Transparency”
3. referential electrode – “free”
4. whole head multichannel system
5. MEG detect tangential components
6. sensitive to the superficial source
7. can be repeated
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- NM122 sensor array
- USER'S MANUAL: SYSTEM HARDWARE

Figure 1.11. Layout of the sensor elements. The helmet shaped sensor array is flattened into a plan.
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5. MEG detect tangential components

Fig. 2  Cells oriented perpendicular to the skull (A) fail to generate an extracranial magnetic field. Cells oriented parallel to the skull (B) produce a significant radial magnetic field. Cells of intermediate orientation (C) have both radial and tangential current components.

I : electric current  
B : magnetic field
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\[ B = \frac{\mu_0}{4\pi} \bar{Q} \times \bar{r} \]

- \( B \) : magnetic field magnitude of a current dipole
- \( \mu_0 \) : permeability of free space
- \( Q \) : current dipole
- \( r \) : distance from current dipole to location at measured area
1. noninvasive technique
2. brain conductivity – “Transparency”
3. referential electrode – “free”
4. whole head multichannel system
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MEG

Non-invasive recording
- Direct measurement of brain electrophysiology (esp. sulcus, superficial area)
- Less distortion and smearing effect by inhomogeneity
- Adequate sampling by more than 100 sensors

Functional – Structural relationships
- with milimeter and millisecond precision (good temporal and spatial resolution)
Limitations

- magnetic current (field) characters
  1) distance effect
  2) sulcus & gyrus
- measurement
  3) ictal / interictal event
  4) motion artifact
  5) cost problem

The MEG and EEG should be combined
Spike Detectability of Partial Epilepsy on Lateral Convexity:
Whole Head Magnetoencephalography vs 10-20 Conventional EEG

HyeonMi Park,
*Nobukazu Nakasato,
**Masaki Iwasaki, *Hiroshi Shamoto, **Takashi Yoshimoto

Dept. of Neurology, Ghil Medical Center, Gachon Medical School, *Dept. of Neurosurgery, Kohnan Hospital, and Dept. of Neurosurgery, Tohoku University Graduate School of Medicine
EEG
## Summary of Spike detectability

<table>
<thead>
<tr>
<th>Patient N.</th>
<th>Total N. of Spikes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49</td>
</tr>
<tr>
<td>2</td>
<td>52</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>51</td>
</tr>
<tr>
<td>6</td>
<td>49</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>56</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>51</td>
</tr>
<tr>
<td>11</td>
<td>17</td>
</tr>
</tbody>
</table>

Spikes only detected by MEG may be related to the higher sensitivity of MEG to currents tangential to the scalp. The scalp potential distribution due to a single tangential current is more diffuse and distorted than the scalp magnetic field distribution. Focal epileptic discharge may easily overlap with the surrounding normal brain noise. In contrast, the spatial gradiometers of MEG are useful to separate the focal abnormality from the background activity [1]. The coarser sensor density of scalp EEG may be another reason for the lower detectability. However, we believe that denser electrode placement would not overcome the theoretical disadvantages of scalp EEG, that is the "smearing effect" caused by the inhomogeneous head conductivity.
Summary of Spike detectability

Spikes only detected by EEG may be related to the higher sensitivity of EEG to currents radial to the scalp. However, the cortical source of a single spike discharge may be larger than the gyral width, so the neighboring sulcal cortex may generate a tangential current from the spike activity that might be detectable by MEG. EEG also has a higher specificity to detect epileptic discharges than MEG. Under some conditions, MEG may detect multiple spike activity over a large cortical area, whereas scalp EEG may summarize multiple spike activity into a single spike or sharp discharge. The present study found that the higher spatial resolution of MEG could not define single spike activity, since more strict criteria were used for the MEG spikes than the EEG spikes. Introduction of advanced models to estimate multiple sources may increase spike detectability by MEG.
Fig. 2. EEG and MEG spike population in 40 patients with epileptic spikes

(Iwasaki et al. 2002)
Comparison of Magnetoencephalographic Spikes With and Without Concurrent Electroencephalographic Spikes in Extratemporal Epilepsy

Hyeon-Mi Park
Department of Neurosurgery, Tohoku University Graduated School of Medicine

Tohoku Exp. Med, 2004
A: E/M-spike
B: M-spike
Location of the spike ECD

No significant difference in ECD location between M-spikes and E/M-spikes

<table>
<thead>
<tr>
<th></th>
<th>X/mm</th>
<th>Y/mm</th>
<th>Z/mm</th>
<th>Q/nAm*</th>
</tr>
</thead>
<tbody>
<tr>
<td>E/M-spike</td>
<td>41.2</td>
<td>29.7</td>
<td>67.2</td>
<td>316.9</td>
</tr>
<tr>
<td>M-spike</td>
<td>46.7</td>
<td>33.1</td>
<td>65.7</td>
<td>137.4</td>
</tr>
</tbody>
</table>

Mean Differences

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>2.1</td>
<td>3.1</td>
<td>3.0</td>
</tr>
</tbody>
</table>
EEG and MEG sensitivity to detect interictal spike discharges

Current Orientation of Spike Source

<table>
<thead>
<tr>
<th>Radial</th>
<th>Oblique</th>
<th>Tangential</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(+)</td>
<td></td>
<td>(point)</td>
</tr>
<tr>
<td>(+)</td>
<td></td>
<td>(small)</td>
</tr>
<tr>
<td>(+)</td>
<td></td>
<td>(large)</td>
</tr>
</tbody>
</table>

- Radial
- Oblique
- Tangential

Brain Noise Level

- M-Spike
- E-Spike
- E/M-Spike

Extension of Active Cortical Area
MEG spikes

1. Localization value of M-spikes is clinically equivalent to that of E/M spike.
2. MEG has equal reliability for the spike detection.
3. The combination of EEG and MEG is useful to detect more interictal spikes in patients with extratemporal epilepsy.
4. The smaller tendency of ECD amplitude of the M-spikes compared with E/M spikes suggests that scalp EEG may overlook small tangential spikes due to background brain noise.
5. MEG may detect spikes of weak tangential current that is invisible in the scalp EEG.
6. MEG may be recommended for interictal spike mapping, especially in patients with infrequent EEG spike.
Cognitive Function Area

- Memory
- Attention
- Language
- Others
Hemispheric Difference of Magnetic Evoked Responses by Monosyllables and Tone Stimuli
-Preliminary Study-

HyeonMi Park, DongJin Shin, Nobukazu Nakasato*, Takashi Yoshimoto*

Dept. of Neurology, Ghil Medical Center, Gachon Medical School, Inchon, Korea
*Dept of Neurosurgery, Tohoku University School of Medicine, Sendai, Japan
Tone

Left

1kHz

Right

1.5kHz
Monosyllable

Left

Right

Ka

Na


Future

- Invasiveness
- Simplicity
- Reproducibility
DSM-1 Tyrannosaurus
Once upon a time......