trudes. Other causes are wide aneurysm neck or loose packing of coils. We could not help ending in such a situation in the acute stage. If a little more coil can be packed into the aneurysm tightly regardless of the coil type, this complication would not occur. Assisting techniques with balloon or stent are effective and used worldwide to reduce migration of the coil. On the other hand, delayed coil migration after embolization has been recently reported. There are two main reasons for the migration. One reason is the stent technique used with the embolization.[2,4] Although stent devices are expected to stably support embolizing coils, fine coils might escape from the stent struts with loose mesh design. The other reason is the combination of the ultrasoft coil, which was recently developed for better embolization, and the balloon remodeling technique.[3,5,8] This technique may simply compress the ultrasoft coils in the coil complex by the balloon. In our case, no stent, balloon, or ultrasoft coil was used. Therefore, our endovascular strategy had less risk of coil migration than previous methods. Coil migration usually occurs during or within a day after the embolization procedure (acute phase). Since vessel endothelium cells might proliferate within a week after treatment, the coils might become stable in the subacute phase. Delayed coil migration, as experienced in the present case, is relatively rare. Surgical removal failed to retrieve the migrated coils because of severe adhesion related to endothelial proliferation and inflammation on the arterial wall. On the basis of our experience, we have to carefully check for coil migration, even some weeks after completing treatment with no negative occurrences.

Our patient had two associated pathological conditions, vasospasm and tortuous cervical ICA. In particular, the tortuous cervical ICA hindered balloon remodeling and fine control of the microcatheter. As a result, the coil packing ratio did not reach adequate values. Such multiple factors might still make endovascular treatment complex. Catheterization to treat peripheral severe tortuous arteries is difficult. Treatment must be planned on the assumption of difficulty in using a balloon in the acute phase, and the possibility of clipping. To employ catheterization to complete treatment without a balloon, we should use a triple coaxial system, such as the Cerulean catheter (Medikit), or the head position should be rotated beforehand to release coiling of the cervical ICA.

The coil placed in the aneurysm was displaced and embolization became incomplete, so we performed craniotomy and clipping to prevent re-rupture. Coil embolectomy, vessel repair, and clipping of the aneurysm are necessary for surgical treatment after such distal coil migration. Coil embolectomy and neck clipping is the optimum treatment strategy. However, removal of intravascular coils is not always possible due to adhesion to the arterial wall. Symptomatic arterial stenosis has been caused by a coil which migrated into the peripheral artery during an operation.[9] Therefore, surgical management that considers even revascularization procedures such as superficial temporal artery-MCA bypass is necessary. Coil manipulation should be carefully performed because the dynamics of coils inserted into the human body are difficult to predict.[9,10]

The present patient with SAH was treated with coil embolization in the spasm phase, but part of a protruding coil migrated distally in the chronic phase. Although endovascular treatment is useful for SAH in the spasm phase, application may be difficult in some cases and should be carefully performed. If a protruding coil is detected at the finish of endovascular treatment, we should consider additional endovascular treatment in the chronic stage. Surgical treatment of a migrating coil may be difficult due to adhesion to the vascular wall.

References

1) Brisman JL, Roonprapunt C, Song JK, Niimi Y, Setton A, Berenstein A, Flamm ES: Intentional partial coil occlusion followed by delayed clip application to wide-necked middle cerebral artery aneurysms in patients presenting with severe vasospasm. Report of two cases. *J Neurosurg* 101: 154-158, 2004
2) Cho CS: Coil migration under stent-assisted embolization. A case report. *Interv Neuroradiol* 12: 65-68, 2006
3) Fiorella D, Kelly ME, Moskowitz S, Masaryk TJ: Delayed symptomatic coil migration after initially successful balloon-assisted aneurysm coiling: technical case report. *Neurosurgery* 64: E391-E392, 2009
4) Gao BL, Li MH, Wang YL, Fang C: Delayed coil migration from a small wide-necked aneurysm after stent-assisted embolization: case report and literature review. *Neuroradiology* 48: 333-337, 2006
5) Haraguchi K, Houkin K, Nonaka T, Baba T: Delayed thromboembolic infarction associated with reconfiguration of Guglielmi detachable coils—case report. *Neurol Med Chir (Tokyo)* 47: 79-82, 2007
6) Meguro T, Sasaki T, Haruma J, Tanabe T, Muraoka K, Terada K, Hirotsune N, Nishino S: [Arterial stenosis after coil migration in embolization of an aneurysm]. *No Shinkei Geka* 38: 41-45, 2010 (Japanese)
7) Morizane A, Nakahara I, Sakai N, Yanamoto H, Akiyama Y, Sakai H, Higashi T, Namura S, Takahashi J, Nishizaki J, Kokuzawa J, Manaka H, Hayashi N, Nagata I, Kikuchi H: [Endovascular surgery for untreated ruptured aneurysm with symptomatic vasospasm]. *No Shinkei Geka* 27: 941-946, 1999 (Japanese)
8) Motegi H, Isobe M, Isu T, Kamiyama H: A surgical case of delayed coil migration after balloon-assisted embolization of an intracranial broad-neck aneurysm: Case report. *Neurosurgery* 67(2 Suppl Operative): 516-521, 2010
9) Phatouros CC, McConachie Ns, Jaspan T: Post-procedure migration of Guglielmi detachable coils and mechanical detachable spirals. *Neuroradiology* 41: 324-327, 1999
10) Thornton J, Dovey Z, Alazzaz A, Misra M, Aletich VA, Debrun GM, Ausman JI, Charbel FT: Surgery following endovascular coiling of intracranial aneurysms. *Surg Neurol* 54: 352-360, 2000

Address reprint requests to: Hajime Wada, MD, Department of Neurosurgery, Asahikawa Medical University, 2-1, 1-1, Midorigaoka-Higashi, Asahikawa, Hokkaido 078-8510, Japan.
e-mail: hjwada@asahikawa-med.ac.jp

Clinical Neurophysiology 123 (2012) 2116–2121

Contents lists available at SciVerse ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Invited review

Publication criteria for evoked magnetic fields of the human brain: A proposal

Isamu Ozaki [a,*], Hideaki Shiraishi [b], Kyousuke Kamada [c], Shigeki Kameyama [d], Naohiro Tsuyuguchi [e], Masato Yumoto [f], Yutaka Watanabe [g], Masayuki Hirata [h], Ryouhei Ishii [i], Yoshinobu Iguchi [j], Tomoaki Kimura [k], Ryosuke Takino [l], Isao Hashimoto [m]

[a] Faculty of Health Sciences, Aomori University of Health and Welfare, 58-1 Mase, Hamadate, Aomori 030-8505, Japan
[b] Department of Pediatrics, Hokkaido University Graduate School of Medicine, Sapporo 060-8638, Japan
[c] Department of Neurosurgery, Asahikawa Medical University, Asahikawa 078-8510, Japan
[d] Nishi-Niigata Chuo National Hospital, Niigata 950-2085, Japan
[e] Department of Neurosurgery, Osaka City University Graduate School of Medicine, Osaka 545-8586, Japan
[f] Department of Clinical Laboratory, Graduate School of Medicine, The University of Tokyo, Tokyo 113-8655, Japan
[g] Department of Psychiatry, National Center Hospital of Neurology and Psychiatry, Tokyo 187-8551, Japan
[h] Department of Neurosurgery, Osaka University Graduate School of Medicine, Osaka 565-0871, Japan
[i] Department of Psychiatry, Osaka University Graduate School of Medicine, Osaka 565-0871, Japan
[j] Integrated Neuroscience Research Project, Tokyo Metropolitan Institute of Medical Science, Tokyo 156-8506, Japan
[k] Department of Acupuncture and Moxibustion, Tokyo Ariake University of Medical and Health Sciences, Tokyo 135-0063, Japan
[l] Department of Developmental and Clinical Psychology, Shiraume Gakuen University, Tokyo 187-8570, Japan
[m] Kanazawa Institute of Technology, Tokyo 102-0083, Japan

ARTICLE INFO

Article history:
Accepted 2 June 2012
Available online 24 July 2012

Keywords:
Axial gradiometer
Planar gradiometer
MEG
Stimulus-evoked MEG
Magnetic fields
Publication criteria
A region of interest
A root mean-squared (RMS) waveform
A contour map
A normal database

HIGHLIGHTS

- In this article, we propose publication criteria for studies of an evoked or event-related magnetoencephalogram (MEG).
- The criteria include original waveforms and a root mean-squared waveform in a region of interest with a contour map at an appropriate time.
- This three set of presentations will allow comparison of evoked or event-related MEG signals recorded with different MEG sensors.

ABSTRACT

Magnetoencephalography (MEG) is a record of the magnetic fields produced by the electrical activities of the brain using MEG systems. There are three types of sensors for MEG systems: magnetometer and two types of gradiometer. Among them, two types of gradiometer, axial and planar, have been used worldwide. Unfortunately, the waveforms recorded by the two types of gradiometer are often different from each other. This poses a serious problem in comparing and evaluating the data from the two gradiometers. We consider that the MEG study should be published in a way that allows other workers using different types of gradiometer to evaluate and replicate the results of MEG studies. There have been, however, no publication criteria for reports of studies on stimulus-evoked or event-related magnetic fields in human subjects. In this article, we propose publication criteria for evoked or event-related magnetic fields of the human brain: original waveforms of selected channels covering a region of interest, a root mean-squared (RMS) waveform and a contour map at an appropriate time.

Contents

* Corresponding author. Address: Faculty of Health Sciences, Aomori University of Health and Welfare, 58-1 Mase, Hamadate, Aomori 030-8505, Japan. Tel.: +81 17 765 2070; fax: +81 17 765 2188.
E-mail address: isamu@auhw.ac.jp (I. Ozaki).

1388-2457/$36.00
http://dx.doi.org/10.1016/j.clinph.2012.06.008

1. Introduction

Magnetoencephalography (MEG) is a totally non-invasive technique for providing spatially and temporally accurate information about the distribution of current sources in the cerebral cortex. Spatial resolution of MEG is considered superior to that of scalp electroencephalography (EEG), because magnetic fields recorded outside the scalp are unaffected by the electrical and geometrical properties of brain, skull and scalp. MEG can visualise travelling impulses from the thalamus to the primary somatosensory cortex (Kimura et al., 2008), but it has been believed insensitive to radially oriented currents; activated area confined to the cortex of a certain geometry that produces radially oriented currents, such as gyral cortices of the lateral surface of the brain, can be overlooked in MEG records. As to clinical application of MEG for epilepsy, MEG is reportedly limited to detect spikes originating from mesial temporal lobes based on a combination study of electrocorticogram (cortical EEG) and MEG (Agirre-Arrizubieta et al., 2009). In this sense, one should be modest about accuracy regarding the spatial resolution of MEG. Further, as compared to EEG, MEG has a great disadvantage of much higher cost for maintenance such as keeping an appropriate level of liquid helium; a recycling system for helium at each MEG facility is awaited from an economical and ecological point of view.

Nevertheless, the total non-invasiveness of MEG has the benefit of repeat examinations in patients suffering from epilepsy or progressive neurodegenerative diseases and children with such diseases. However, MEG has not been either widely used or reached a high status for a functional brain mapping method as yet, though the number of MEG facilities was gradually increased worldwide (more than 140 in the year 2011). It is more than 30 years since MEG was introduced to basic and applied neuroscience, but standardisation of the MEG technique, which includes a recording or stimulating procedure of MEG and publication criteria of results, has not been established. This may have caused MEG to meet with severe criticism from inside and outside the MEG community; among the published papers on MEG, though novel, some articles are not rigorous enough because no original waveforms of MEG but a root mean-squared (RMS) waveform alone or the traces obtained from a couple of sensors (out of 100–200 sensors!) are presented as figures or because, without any MEG waveforms, the location of equivalent current source superimposed onto the subject's brain magnetic resonance imaging (MRI) alone is shown. It seems as if authors of such kind of papers wanted to avoid the results from standing up to a searching scrutiny. Inappropriate presentation of the results in experimental papers does not give the details of how the experiments were carried out and what results were obtained and analysed; therefore, other researchers cannot fully evaluate and replicate the data. As a result, since the year 2005 the number of annual original articles on MEG has begun to plateau.

There are other embarrassing situations in analysis of MEG; one is an inverse problem. At the time when MEG was introduced to neuroscience, a single dipole modelling method was developed to compute localisation of the equivalent current source. It works well for analysing the initial cortical response of stimulus-evoked MEG and localising the equivalent current source. When activated areas are overlapping in a time course or when two or more areas are simultaneously activated, recorded MEG waveforms become more complicated and difficult to analyse by using a single dipole method. Then, many algorithms to calculate the localisation of the multiple equivalent current sources have been published (e.g., for minimum norm estimates, see Hämäläinen and Ilmoniemi, 1994; for spatial filtering, see Taniguchi et al., 2000; and for hierarchical Bayesian estimation, see Sato et al., 2004), but unfortunately, one cannot judge which kind of method among the previously published algorithms is the best to use as their accuracy or correctness has not been proven yet by a proper method between the researchers. In fact, a recent bibliographic survey on the clinical application of MEG for epilepsy has disclosed that a single dipole method is commonly used to verify accuracy of MEG in localisation of epileptogenesis as compared to other methods such as cortical EEG (Hirata et al., 2012). Another problematic issue in MEG is that several different sensors for MEG systems have been developed to pick up magnetic flux from the outside of the brain: a magnetometer and two types of gradiometer. Among them, two types of gradiometer, axial and planar, have been used worldwide. However, the waveforms of individual MEG sensors inherently differ between the two types of gradiometer; for the planar gradiometer (Elekta Neuromag VV (Elekta Oy, Helsinki, Finland)), the response with the maximal amplitude is recorded from the sensor located just above the equivalent current source; for the axial gradiometer, the maximal positive and negative responses are obtained from a pair of sensors apart from each other that sandwiches the equivalent current source. Whereas a unit of amplitude of EEG waveforms is the 'micro Volt' regardless of which EEG equipment is used for recording, a unit of amplitude of MEG waveforms differs between the two types of gradiometer: 'femto Tesla' in the axial gradiometer and 'femto Tesla/cm' in the planar gradiometer. Therefore, when looking at responses from individual sensors, original MEG waveforms alone are inadequate for evaluating and replicating evoked-MEG responses. As a result, users of an axial gradiometer sometimes cannot appropriately evaluate the results of MEG recorded from the planar gradiometer, and vice versa. Furthermore, as previously described, some researchers of the MEG demonstrate an RMS waveform alone in an article (see Haueisen et al., 2000); and others do not show any waveforms (see Mogilner et al., 1993; Elbert et al., 1995; Braun et al., 2000; Breier et al., 2004; Periáñez et al., 2004). Therefore, neuroscientists or physiologists both familiar and unfamiliar with MEG cannot fully evaluate some of the results on MEG that have been published. Perhaps, the situations described above have made it difficult to conduct a multicentre study on MEG or to expand clinical application of MEG testing. To make the MEG become a more favourable and reliable tool for mapping human brain function, we consider it obligatory to find a way to present MEG data common to the two different MEG systems, to build a consensus on the minimum requirement for publication criteria of MEG data and thereby, to allow workers to compare and replicate the results of published MEG data easily.

2. Recommended representation of evoked MEG data

For the analyses of stimulus-evoked MEG, we use the following information: original waveforms obtained from sensors, the iso-

contour field distributions of the magnetic field representing flux-out and flux-in at a certain time, orientation and location of an equivalent current source that produces a recorded magnetic field and results of spatial filtering such as Beamformer (Sekihara et al., 2001) and LORETA (Pascual-Marqui et al., 1994). Among various methods of MEG-data presentation, we consider it preferable to represent original waveforms of selected channels covering a region of interest, an RMS waveform in the region of interest and an isocontour field map at a certain time for evoked MEG as this three set of presentations will be shared between the axial and the planar gradiometer systems.

2.1. The need for presenting raw records: original waveforms of selected channels covering a region of interest and an RMS waveform in the region of interest

As emphasised in the publication criteria for studies of evoked potential (EP) (Donchin et al., 1977), an absolute acceptance criterion for all papers on stimulus-evoked MEG should be that they include actual records of averaged MEG waveforms. It is not required to publish all data of experiments; it is the authors' responsibility to select data to be presented, but figures should honestly reflect the quality of the data collected. It is also important to represent replications of the records under the same conditions to confirm reproducibility of the results and indicate the quality of the recording process. For EEG recording, as electrode placements are determined according to the International 10–20 system and are unchanged during experiments, it has been recommended to show duplication of representative waveforms at a certain electrode placement for two or more trials: for example, superimposed waveforms recorded from the Cz electrode for auditory evoked or event-related potentials (ERPs) or those obtained from the C3/4 electrode for somatosensory-evoked potentials after median nerve stimulation. In the case of recording MEG, sensor placements are fixed on the dewar but not on the subject's head so that sensor positions relative to the subject's head are changeable from one trial to another when the subject moves his or her head even a little within a dewar during an experiment. It is, therefore, quite difficult to choose a particular sensor channel for demonstrating a representative MEG waveform and to show superimposed records obtained from the particular sensor channel. In addition, as described previously, the response waveforms of individual sensors inherently differ between the planar and the axial gradiometer. For the planar gradiometer, the response with the maximal amplitude is recorded from the sensor located just above the equivalent current source; polarity change of the waveform directly indicates the opposite direction of the equivalent current dipole. For the axial gradiometer, the maximal positive and negative responses are obtained from a pair of sensors apart from each other that sandwiches the equivalent current source; a polarity change from positive to negative in the waveform at a certain sensor indicates the change from magnetic flux-out to flux-in across the scalp. Hence, to demonstrate raw MEG records that can be shared between users of a planar gradiometer and those of an axial gradiometer, we suggest that one should represent original waveforms of selected channels covering a region of interest in the case of stimulus-evoked or event-related MEG. When they are presented as superimposed records, the figure will reflect the quality of the data collected. In addition to original waveforms of selected channels covering a region of interest, we suggest that an RMS waveform should be presented because it easily shows culmination of a stimulus-evoked MEG response. To show replication of the results under the same conditions, two sets of the superimposed raw records obtained from selected channels covering a region of interest will be presented; or the calculated RMS waveforms for two trials can be superimposed.

2.2. The need for presenting spatial distribution of the magnetic field at an appropriate time: an isocontour field map representing flux-out and flux-in at a peak latency of an RMS waveform

The raw traces recorded from individual sensor channels show sequential changes of magnetic fields at their sensor placements; the RMS waveform obtained from selected channels covering a region of interest represents a global time-course of the stimulus-evoked or event-related brain responses. However, analysing spatial distribution of the electromagnetic field at an appropriate time is essential to know which area or areas in the brain are activated. Isocontour field distributions of the magnetic field representing flux-out and flux-in are very informative; when a response consists of a single equivalent current dipole, the isocontour field distributions of the magnetic field represent a pair of flux-out and flux-in; when a response consists of more than two equivalent current dipoles, they may show a complex pattern such as two or more pairs of flux-out and flux-in. Therefore, we suggest that isocontour field maps should be presented at a certain time such as a peak latency of an RMS waveform or at several successive times including an RMS peak.

2.3. Demonstration of examples of somatosensory- or auditory-evoked MEG signals

Fig. 1 illustrates somatosensory-evoked magnetic fields (SEFs) following left median nerve stimulation obtained from a representative subject, using an axial gradiometer system (A) or a planar gradiometer system (B). Looking at a topographic display of recorded MEG waveforms, spatial distributions of maximum and/or minimum responses and shapes of the MEG waveforms in a certain region differ between an axial gradiometer system and a planar gradiometer system. However, superimposed waveforms or RMS waveforms of the right hemisphere obtained by an axial gradiometer system and by a planar gradiometer system are quite similar. So are isocontour field distributions of the magnetic field at the peak latency of N20 m. Another example is demonstrated in Fig. 2 in which auditory-evoked magnetic fields (AEFs) following left ear 1000 Hz tone-burst stimulation are obtained from the subject as in Fig. 1, using an axial gradiometer (A) or a planar gradiometer (B). Isocontour field distributions of the magnetic field at the peak latency of N1 m, superimposed waveforms and RMS waveforms that are obtained by an axial gradiometer system are compatible with those obtained by a planar gradiometer system, though the sensor layout display of recorded MEG waveforms differs between the two systems.

3. Discussion

Stimulus-evoked or event-related changes in the electromagnetic fields of the brain can be extracted from the ongoing spontaneous MEG or EEG by means of filtering and signal averaging. As to ERPs or EPs, the guidelines for recording standards and publication criteria were proposed (Donchin et al., 1977; Picton et al., 2000) and have been recommended by the International Federation of Clinical Neurophysiology (IFCN) (for visual EPs, see Celesia et al., 1993; for auditory ERPs, see Goodin et al., 1994; for somatosensory-evoked potentials, see Nuwer et al., 1994) or by the American Clinical Neurophysiology Society (2006a–d). Further, the recommendations by IFCN for the clinical use of various EPs or ERPs have been updated (Cruccu et al., 2008; Duncan et al., 2009; Holder et al., 2010). As for MEG, the clinical practice guideline for MEG is proposed by the Japanese Society of Clinical Neurophysiology (Hashimoto et al., 2005) and by the American Clinical Magnetoencephalography Society (Bagić et al., 2011a,b; Burgess et al., 2011).

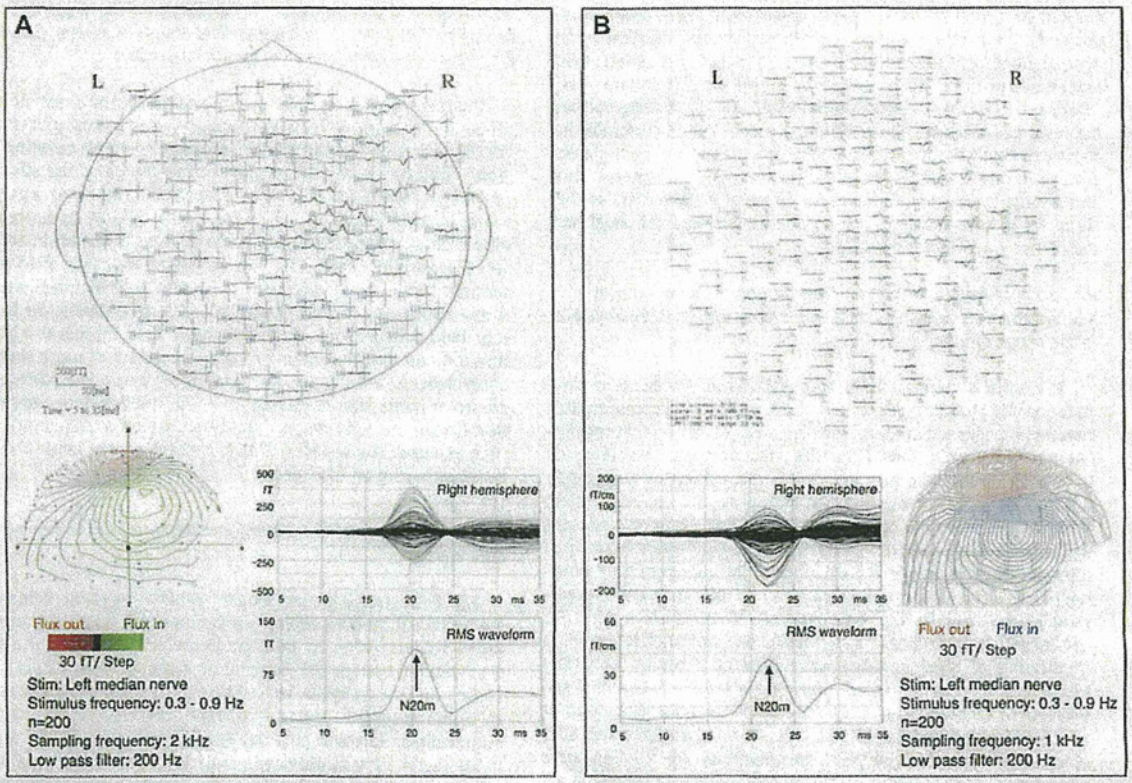

Fig. 1. Somatosensory evoked magnetic fields (SEF) following left median nerve stimulation obtained from a representative subject using an axial gradiometer system (A) (Yokogawa, MEGVision) or a planar gradiometer system (B) (Neuromag, Vector View). Upper column: sensor layout display of SEF waveforms (post-stimulus period of 5–35 ms). Lower column: right lateral view of isocontour field distributions of the magnetic field at the peak latency of N20 m, superimposed SEF waveforms and root mean squared (RMS) waveforms. Note that, although SEF waveforms at individual measurement sites and their spatial distribution differ between the axial and planar gradiometer systems, superimposed SEF waveforms, root mean squared (RMS) waveforms and contour maps are similar to each other.

These guidelines include technical issues in relation to recording and stimulating methods, the majority of which follow the practical standards for EEG, such as EPs and ERPs. Although the publication criteria for EPs emphasise the necessity for raw records of averaged EPs (Donchin et al., 1977; Picton et al., 2000), there have been no publication criteria for MEG: presentation of MEG waveforms as well as analysed MEG data. Here, for the first time we have proposed the publication criteria for stimulus-evoked or event-related MEG as the three set of presentations: original waveforms of selected channels covering a region of interest, an RMS waveform in the region of interest and an isocontour field map at a certain time for evoked MEG. As shown in examples of SEFs and AEFs (Figs. 1 and 2), the three set of presentations will allow investigators of MEG to share the results of evoked MEG. Similar to EPs or ERPs in EEG, the publication criteria for stimulus-evoked MEG or event-related MEG we propose will help not only neurophysiologists to examine patients by means of MEG testing and make a diagnosis of a neurological disease, but also scientists to evaluate and replicate previously published MEG data.

In general, developing a standardised method for data analysis accelerates propagation of a new research technology. In 1990, Ogawa et al. developed a new technique, using functional magnetic resonance imaging (fMRI) to provide focal haemodynamic changes in the brain of humans and animals (Ogawa et al., 1990), but it was not until the statistical parametric mapping (SPM) software was developed as a standardised method for analysis of brain MRI (Friston, 1995) that fMRI was used explosively for mapping the working brain. We think, therefore, that a standardised method for data analysis of MEG, such as the SPM for fMRI, is needed for propagation of MEG. As different types of sensors detecting MEG signals are commonly used, the most practical approach is to transform recorded magnetic signals from the brain into a virtual standard sensor configuration, as has been previously attempted for magnetocardiography (Burghoff et al., 2000). If all recorded magnetic signals from the brain are converted into signals of a virtual standard MEG system, direct comparison of signals obtained from different MEG recording devices will be available. However, apart from the impulse conduction system of the heart, there exists large intersubject variability in the sulci of the brain, confounding the transformation approach for MEG signals. The alternative transformation approach for each subject in which magnetic signals obtained from MEG sensors are converted into signals on the subject brain MRI will avoid intersubject variability in the sulci of the brain. However, this approach inevitably needs the brain MRI of the subject who undergoes MEG testing. In addition, there has been no consensus on building a virtual standard MEG system so that transforming recorded signals to source space via a localisation algorithm, or to signals of the virtual standard MEG system, awaits a general agreement. Currently, we have no choice other than to present signals from the sensors that are fixed within a dewar of an MEG system; the locations and types of the sensors differ among MEG recording devices. Therefore, we consider that our

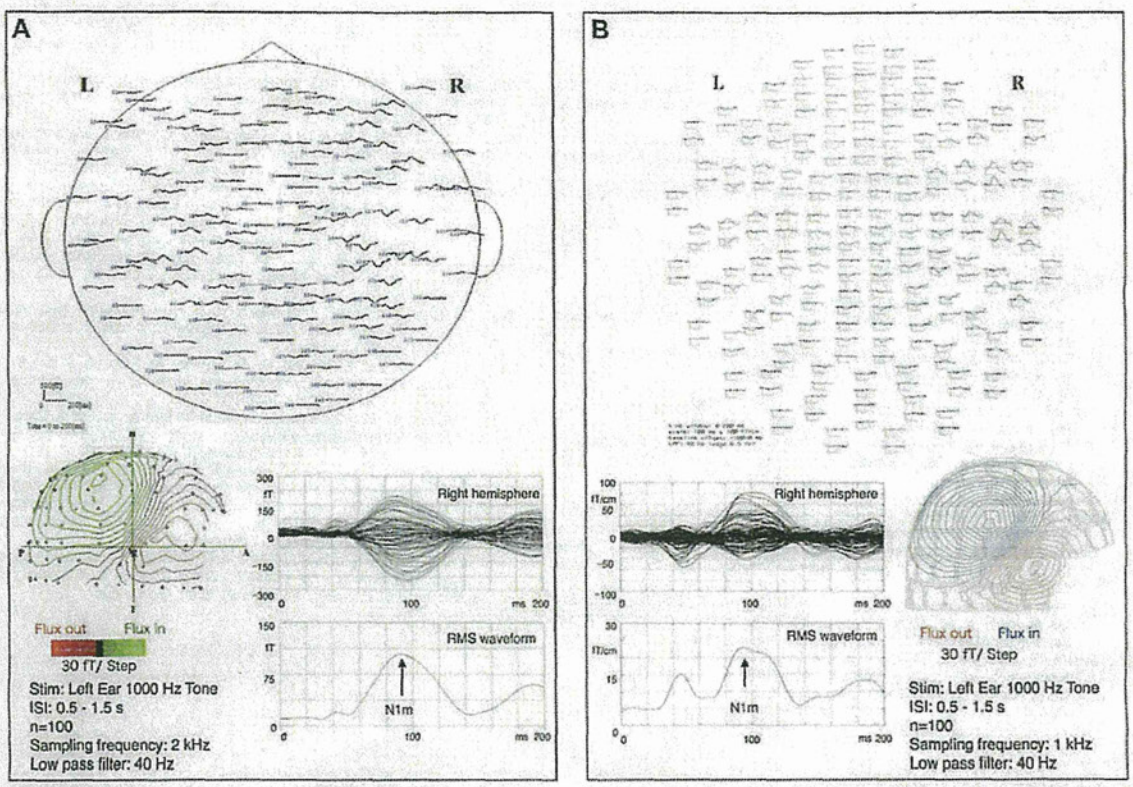

Fig. 2. Auditory evoked magnetic fields (AEFs) following left ear 1000 Hz tone burst stimulation obtained from a representative subject using an axial gradiometer system (A) (Yokogawa, MEGVision) or a planar gradiometer system (B) (Neuromag, Vector View). Upper column: sensor layout display of AEF waveforms (post-stimulus period of 200 ms). Lower column: right lateral view of isocontour field distributions of the magnetic field at the peak latency of N1 m, superimposed AEF waveforms and root mean squared (RMS) waveforms. Note that, although AEF waveforms at individual measurement sites and their spatial distribution differ between the axial and planar gradiometer systems, superimposed AEF waveforms, root mean squared (RMS) waveforms and contour maps are similar to each other.

proposal on publication criteria, comprising original waveforms of selected channels covering a region of interest, an RMS waveform in the region of interest and an isocontour field map at an appropriate time(e.g., an RMS peak), will allow comparison of event-related or stimulus-evoked MEG signals recorded with different MEG recording devices. This will specify minimal acceptance criteria for reports of studies in patients or normal humans. We hope that our proposal should facilitate conducting a multicentre study and building a normal database of stimulus-evoked and event-related MEGs in the near future, and that a standardised diagnostic protocol of MEG based on the normal database will be established, thereby enhancing clinical utility of MEG.

Acknowledgements

This article is based on the discussion at the International Symposium on Standardization of Magnetoencephalography that was held in Kanazawa, Japan, 27 May 2009. The authors thank Drs. Martin Burghoff, Ron Wakai, Jens Haueisen, Ying-Zu Huang, Yoshio Okada, Chun Kee Chung, Risto Ilmoniemi, Yung-Yang Lin, Anti Ahonen and Andrew C. Papanicolaou for their helpful advice. This work was supported by Ishikawa High-Tech Sensing Cluster, Hokuriku Innovation Cluster for Health Science, Research Program of JPN Ministry of Education and Science for the Standardization of MEG and KAKENHI 23500599 (Grant-in-Aid for Scientific Research (C)).

References

Agirre-Arrizubieta Z, Huiskamp GJ, Ferrier CH, van Huffelen AC, Leijten FS. Interictal magnetoencephalography and the irritative zone in the electrocorticogram. Brain 2009;132:3060–71.

American Clinical Neurophysiology Society. Guideline 9A: guidelines on evoked potentials. J Clin Neurophysiol 2006a;23:125–37.

American Clinical Neurophysiology Society. Guideline 9B: guidelines on visual evoked potentials. J Clin Neurophysiol 2006b;23:138–56.

American Clinical Neurophysiology Society. Guideline 9C: guidelines on short-latency auditory evoked potentials. J Clin Neurophysiol 2006c;23:157–67.

American Clinical Neurophysiology Society. Guideline 9D: guidelines on short-latency somatosensory evoked potentials. J Clin Neurophysiol 2006d;23:168–79.

Bagić AI, Knowlton RC, Rose DF, Ebersole JS, ACMEGS Clinical Practice Guideline (CPG) Committee. American Clinical Magnetoencephalography Society Clinical Practice Guideline 1: recording and analysis of spontaneous cerebral activity. J Clin Neurophysiol 2011a;28:348–54.

Bagić AI, Knowlton RC, Rose DF, Ebersole JS, ACMEGS Clinical Practice Guideline (CPG) Committee. American Clinical Magnetoencephalography Society Clinical Practice Guideline 3: MEG-EEG reporting. J Clin Neurophysiol 2011b;28:362–3.

Braun C, Wilms A, Schweizer R, Godde B, Preissl H, Birbaumer N. Activity patterns of human somatosensory cortex adapt dynamically to stimulus properties. Neuroreport 2000;11:2977–80.

Breier JI, Castillo EM, Boake C, Billingsley R, Maher L, Francisco G, et al. Spatiotemporal patterns of language-specific brain activity in patients with chronic aphasia after stroke using magnetoencephalography. Neuroimage 2004;23:1308–16.

Burgess RC, Funke ME, Bowyer SM, Lewine JD, Kirsch HE, Bagić AI. ACMEGS Clinical Practice Guideline (CPG) Committee. American Clinical Magnetoencephalography Society Clinical Practice Guideline 2: presurgical functional brain mapping using magnetic evoked fields. J Clin Neurophysiol 2011;28:355–61.

Burghoff M, Nenonen J, Trahms L, Katila T. Conversion of magnetocardiographic recordings between two different multichannel SQUID devices. IEEE Trans Biomed Eng 2000;47:869–75.
Celesia GG, Bodis-Wollner I, Chatrian GE, Harding GF, Sokol S, Spekreijse H. Recommended standards for electroretinograms and visual evoked potentials. Report of an IFCN committee. Electroencephalogr Clin Neurophysiol 1993;87:421–36.
Cruccu G, Aminoff MJ, Curio G, Guerit JM, Kakigi R, Mauguiere F, et al. Recommendations for the clinical use of somatosensory-evoked potentials. Clin Neurophysiol 2008;119:1705–19.
Donchin E, Callaway E, Cooper W, Desmedt JE, Goff WF, Hillyard SA, et al. Publication criteria for studies of evoked potentials (EP) in man: report of a committee. In: Desmedt JE, editor. Attention, Voluntary Contraction and Event-Related Cerebral Potentials. Progress in Clinical Neurophysiology 1977;vol. 1. Basel: Karger; 1977. p. 1–11.
Duncan CC, Barry RJ, Connolly JF, Fischer C, Michie PT, Näätänen R, et al. Event-related potentials in clinical research: guidelines for eliciting, recording, and quantifying mismatch negativity, P300, and N400. Clin Neurophysiol 2009;120:1883–908.
Elbert T, Pantev C, Wienbruch C, Rockstroh B, Taub E. Increased cortical representation of the fingers of the left hand in string players. Science 1995;270:305–7.
Friston KJ. Commentary and opinion: II. Statistical parametric mapping: ontology and current issues. J Cereb Blood Flow Metab 1995;15:361–70.
Goodin D, Desmedt J, Maurer K, Nuwer MR. IFCN recommended standards for long-latency auditory event-related potentials. Report of an IFCN committee. International Federation of Clinical Neurophysiology. Electroencephalogr Clin Neurophysiol 1994;91:18–20.
Hämäläinen MS, Ilmoniemi RJ. Interpreting magnetic fields of the brain: minimum norm estimates. Med Biol Eng Comput 1994;32:35–42.
Hashimoto I, Kakigi R, Nagamine T, Nakasato N, Shiraishi H, Watanabe Y. Guideline for Clinical Application of Magnetoencephalography. Jpn J Clin Neurophysiol 2005;33:231–52.
Haueisen J, Heuer T, Nowak H, Liepert J, Weiller C, Okada Y, et al. The influence of lorazepam on somatosensory-evoked fast frequency (600 Hz) activity in MEG. Brain Res 2000;874:10–4.
Hirata M, Kameyama S, Goto T, Yanagisawa T, Kishima H, Oscine S, et al. Bibliographic survey on the clinical application of magnetoencephalography (I): epilepsy. Jpn J Clin Neurophysiol 2012;40:140–6.
Holder GE, Celesia GG, Miyake Y, Tobimatsu S, Weleber RG. International Federation of Clinical Neurophysiology. International Federation of Clinical Neurophysiology: recommendations for visual system testing. Clin Neurophysiol 2010;121:1393–409.
Kimura T, Ozaki I, Hashimoto I. Impulse propagation along thalamocortical fibers can be detected magnetically outside the human brain. J Neurosci 2008;28:12535–8.
Mogilner A, Grossman JA, Ribary U, Joliot M, Volkmann J, Rapaport D, et al. Somatosensory cortical plasticity in adult humans revealed by magnetoencephalography. Proc Natl Acad Sci USA 1993;90:3593–7.
Nuwer MR, Aminoff M, Desmedt J, Eisen AA, Goodin D, Matsuoka S, et al. IFCN recommended standards for short latency somatosensory evoked potentials. Report of an IFCN committee. International Federation of Clinical Neurophysiology. Electroencephalogr Clin Neurophysiol 1994;91:6–11.
Ogawa S, Lee TM, Kay AR, Tank DW. Brain magnetic resonance imaging with contrast dependent on blood oxygenation. Proc Natl Acad Sci USA 1990;87:9868–72.
Pascual-Marqui RD, Michel CM, Lehmann D. Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. Int J Psychophysiol 1994;18:49–65.
Periáñez JA, Maestú F, Barceló F, Fernández A, Amo C, Ortiz Alonso T. Spatiotemporal brain dynamics during preparatory set shifting: MEG evidence. Neuroimage 2004;21:687–95.
Picton TW, Bentin S, Berg P, Donchin E, Hillyard SA, Johnson Jr R, et al. Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. Psychophysiology 2000;37:127–52.
Sato MA, Yoshioka T, Kajihara S, Toyama K, Goda N, Doya K, et al. Hierarchical Bayesian estimation for MEG inverse problem. Neuroimage 2004;23:806–26.
Sekihara K, Nagarajan SS, Poeppel D, Marantz A, Miyashita Y. Reconstructing spatio-temporal activities of neural sources using an MEG vector beamformer technique. IEEE Trans Biomed Eng 2001;48:760–71.
Taniguchi M, Kato A, Fujita N, Hirata M, Tanaka H, Kihara T, et al. Movement-related desynchronization of the cerebral cortex studied with spatially filtered magnetoencephalography. Neuroimage 2000;12:298–306.

てんかんをめぐって 31:51-60, 2012

総　説　北海道てんかん懇話会35周年記念シンポジウム：てんかん学の新知見

脳皮質電位による認知機能野の局在解析

鎌田　恭輔、佐藤　正夫

要　旨

異なる視覚刺激により脳表を覆った頭蓋内電極よりElectrocorticogram（ECoG）を計測した。ECoGの時間－周波数解析により、側頭葉底部では視覚刺激が単純であるほど後頭極側にγ帯域成分が集積した。顔刺激では右優位であり、かつ両側側頭葉底部の前外側にγ帯域成分の増加が広がっていた。物品名称・記憶課題関連ECoGでは記憶課題時に内側側頭葉に刺激提示後500-600msecに80-120Hzのγ帯域成分が有意に上昇していた。このγ帯域成分の上昇のある内側側頭葉に手術を行った4例全例で記銘力障害が出現した。記憶課題により誘発された内側側頭葉のγ帯域成分は記憶機能と密接に関連しているものと考えられた。電極位置の標準化により文字認知では左紡錘状回－海馬傍回に、顔認知では右紡錘状回から下側頭回にγ帯域成分が出現していた。本研究で示したように誘発ECoG計測を解析することにより、今後てんかん術前評価目的の新たなマッピング法として期待できるものと考えられる。

はじめに

我が国のてんかん患者総数は約100万人と推定され、そのうちの20万人は薬剤抵抗性の難治性てんかんとされている。一般に海馬硬化を主体とする典型的内側側頭葉てんかんに対しては、海馬を含む側頭葉切除術により68％で発作消失、24％が改善と良好な結果が得られている[1]。しかし、内側側頭葉てんかん以外の症例には種々の手術法が用いられているが、てんかん焦点の病態の多彩性のため手術効果は様々である[2,3]。この治療ではてんかん学、神経科学が複雑に絡み合っているため、その病態、ヒト認知機能局在を明らかにすることで、より確実な治療方針の立案が可能となる。また、昨年の東日本大震災では、てんかんは発作を起こさない限り治療優先度が低いとトリアージされるため、災害時にてんかん患者診療が後回しにされることが問題となった。このため常に国際標準、またはそれ以上のてんかんへの積極的な治療を心がけることが極めて重要である。

難治性てんかんでは画像上の異常がない、または両側性てんかん源性を有する患者では、外科治療のために焦点を電気生理学的に捉えるために頭蓋内電極を留置することが多い。通常は

旭川医科大学　脳神経外科学講座（〒078-8510 北海道旭川市緑が丘東２条１丁目１－１）

この留置した頭蓋内電極により、てんかん発射源の同定、および脳皮質電気刺激による言語機能マッピングを行っている。

本申請では頭蓋内電極より様々な課題を行うことで、運動、言語関連、記憶関連機能の画像化を試みた。個々の患者において行った課題、提示刺激で誘発された脳皮質電位(Electrocorticogram:ECoG)の時間・空間的広がりのパターン化を行った。特に記憶関連ECoGの有無と手術による記憶障害出現程度について比較した。さらに複数の自動判別関数を用いて課題別ECoG反応のClassificationに応用し、より効率的な脳信号の抽出を試みた。また、患者間で留置電極位置にばらつきがあるため、標準脳にECoG電極位置座標を変換・重畳した。これにより標準脳上に高解像のECoGの時間的変化過程を描画した。これらを組み合わせることにより、言語、記憶機能野の同定、および典型的な認知ECoG反応ダイナミクスを解析する方法を開発したので報告する。

対象および方法

対象：旭川医科大学病院と関連施設において難治性てんかん外科治療のために頭蓋内電極を留置した20例を対象にした。患者の内訳は、側頭葉てんかん16例、前頭葉てんかん3例、後頭葉てんかん1例であった。患者年齢は32.4±10.3歳であり、男女比は9:11であった。全例Wada testを施行し言語優位半球，記憶優位半球（言語性，視覚性）を同定した。また術前にWAIS-R、WMS-Rを全例に施行し高次機能評価を行った。

頭蓋内電極留置：てんかんの焦点精査目的に両側側頭葉底面，前頭葉外側面，側頭葉外側面などに硬膜下電極を留置した。側頭葉内側（鈎から海馬傍回にかけて）に留置した8極電極は術中に透視で位置を確認した。

術前MRIから脳表データをDr.View（AJS、日本）を用いて抽出した。電極位置が含まれる術後CTデータはDr.Viewにより術前MRI座標に変換してリスライスを行った。座標の一致している術前MRIと術後CTをEMSE(Source Signal Imaging、米）上で脳表と電極位置と融合表示し、電極位置はすべて番号を付して登録した。

頭蓋内電極による誘発ECoG計測：ECoG記録はシールドルーム内でBMSI6000(NicoletBiomedica llnc,Wisconsin、米）脳波計（128ch）を用いて行った。サンプリング周波数は400Hzとした。認知反応課題は①縞模様－アラビア語－単語（平仮名三文字）－顔の視覚提示、②物品呼称（絵を見せて名前を想起)、③記憶課題（あらかじめ検査前に10個の絵を覚え、②の物品呼称で用いたのと同じ絵を含んだ物品群を提示する。②で提示された図と判断した時は、非利き手によりボタンを押しを行う。なお②と③の課題の間は15分以上あけて、その間に①の課題を繰り返した。すべての課題は視覚提示時間500msec，刺激提示間隔を2800-3200msec、平均120回の提示回数とした（図1A)。各刺激別にTransister-Transister-logic信号を脳波計チャンネルに入力して、刺激タイミングトリガーとした（図1B)。

ECoG解析：取得ECoGはテキストファイルに変換後Matlab2010b+ Simulink

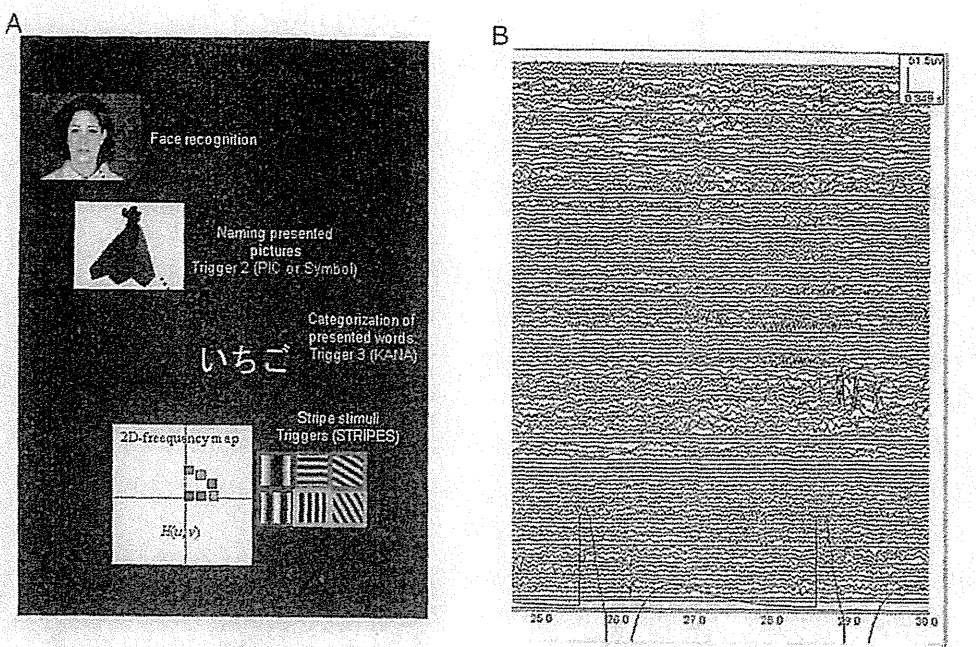

Fig.1 Overview of semantic-ECoG recording. (A) Visual stimuli, (B) Acquired ECoG raw data with TTL signal

(Mathworks, 米) に読み込んだ。Matlab 内のツールを用いて short-time フーリエ変換を行った。刺激提示前 -500msec をベースラインとして、60-120Hz のγ帯域成分が Permutation テスト上統計的に有意 (P<0.05) に変化している電極を選択した。各電極の周波数成分の時間的変化量を解析した。解析結果は EMSE 上で登録した電極にカラーマップとして表示して、γ帯域成分の時間 - 空間的変化を画像化した。

ECoG 標準化：電極位置の標準化は SPM8 (Wellcome Trust Centre for Neuroimaging, 英) を用いて行った。標準脳 MRI に各患者脳 MRI を非線形座標変換により変形する。この変形パラメータを患者頭部 CT データ変換に用いることで、標準脳 MRI 上に各患者 ECoG 電極を重畳する。各電極はすべて番号を付して登録し、γ帯域成分の時間毎の変化量を表示するようにした。1cm 3 単位空間内に分布する電極数で帯域成分値を除すことにより、電極密度分布による成分の空間的広がりを補正した。

結　果

課題遂行度：20症例中12症例ですべての課題を適切に行うことができた。その記憶課題における正当率は平均89.4. ±7.2%であった。

誘発 ECoG 解析結果：

①課題：視覚提示刺激に対する60-120Hz のγ帯域成分の経時的 (150, 175, 300msec)、空間的な広がりを可視化した。典型例を提示す

る。図2は、両側側頭葉底部に電極を留置している症例である。比較的単純な縞模様刺激では150-300msecの間後頭極に活動が限局していた。一方、顔刺激では150msecから両側側頭葉底部均等に活動、300msecになると縞模様刺激に比して右優位、かつ後頭極から前・外側の活動が強くなった。単語読みでは後頭極150msecにやや縞模様刺激より強いγ帯域成分の上昇を認め、最終的に300secでは優位半球（左）の活動が続いた。意味を有していないアラビア語刺激ではじめは単語刺激と同様の反応を認めたが、両側側頭葉底部の活動が続いた。しかし、その活動範囲は顔認知領域に比して内側・後方であった。別の症例では優位半球側頭葉底部に通常の電極間距離10㎜を5㎜とした高密度電極を留置した。同様に縞模様刺激では150-300msecの間後頭極にのみ活動を認めている。顔刺激では300msecほどから側頭葉底面外側にγ帯域成分が広がるのが特徴的であった。一方、単語読み課題では後頭極から側頭葉内側部に活動を認め、外側に広がる顔認知反応と活動パターンが明らかに異なっていた。アラビア語では図2と同様に顔認知と文字認知パターンが混在し、無意味図形に対して側頭葉底部が活発に活動していることが判明した。これらの反応の傾向は計測可能であった12症例全例で同様の傾向であった。

②物品呼称課題と③記憶課題：左内側側頭葉

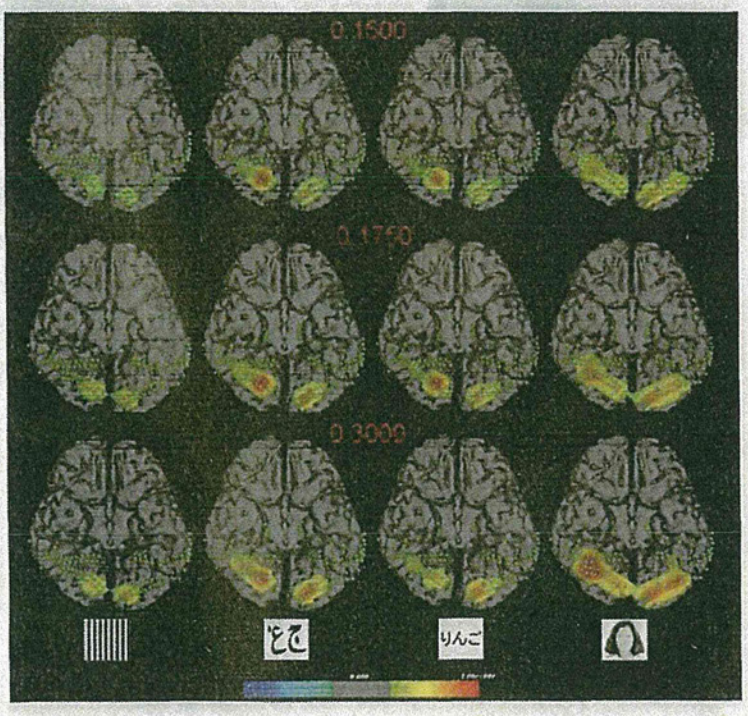

Fig.2 Gamma band map related to different visual stimuli.A patient with ECoG electr4ode on the bilateral temporal bases.Face stimulation excited antero-lateral temporal bases than other stimuli.There are significant differences among visual stimuli.

にγナイフによるRadiosurgeryでRadiation necrosisを生じていたが、WMS-Rでは記銘力障害は認めていなかった（図3A）。また、この左側頭葉内側部では電気的活動はほとんど認められなかった。Radiation necrosisのある左側からは電位変化はほとんど無かった。図3B左内側側頭葉の1チャンネルの時間－周波数解析結果である。物品名称課題により活動はほとんど認めなかった。一方記憶課題では潜時500msecを中心として80-120Hzの高周波帯域成分の有意な増加を認めた。

このγ帯域成分が強く現れている側頭葉のてんかん外科手術を行った4例では、術後WMS-R上有意に記銘力低下を認めた。一方γ帯域成分集積の弱い側に外科手術例を行った4例では記憶機能は保たれた。内側側頭葉領域のγ帯域成分の解析は記憶機能の側方性局在を示すものと期待できる。

ECoG標準化：電極位置の標準化は全20症例を用いて行った。標準脳の側頭葉底面、優位半球外側面を1323極の電極で覆うことができた（図4A）。電極密度は下前頭回、上側頭回近傍に高い傾向があった（図4B）が、密度補正を行うことで均一な電極分布状態にすることができた（図4C）。

標準化した結果の視覚刺激別γ帯域成分の分布状態を示す。顔認知（Face）では両側の紡錘状回の前、外側の強い活動を認めた。特に右側への強い側方性があった。一方、文字読み（Kana）では顔認知に比してやや内側の紡錘状回－海馬傍回後部に活動が限局し、右側にはほとんど活動を認めなかった。アラビア語認知（Ara）は右側頭葉底部内側、広範に左側頭葉底部の活動を認めたが、明らかに顔認知、または文字読み課題による反応とは異なっていた（図5）。

考　察

本研究では異なる視覚刺激を提示しながら広範に脳表を覆った頭蓋内電極よりECoGを計

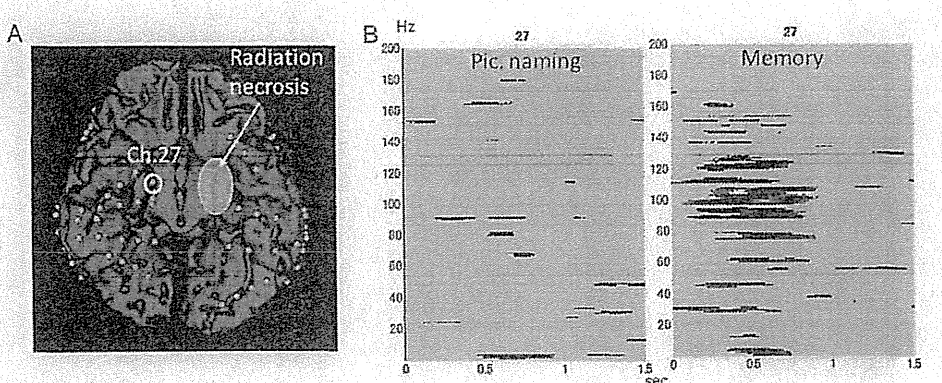

Fig.3 Semantic-ECoG related to memory task. (A) Case 1 with radiation necrosis in the left medial temporal region. (B) Case 2 with left-dominant memory related function. Time-frequency analysis demonstrates significant increase of Gamma-band components around at 500msec after the stimulus onset.

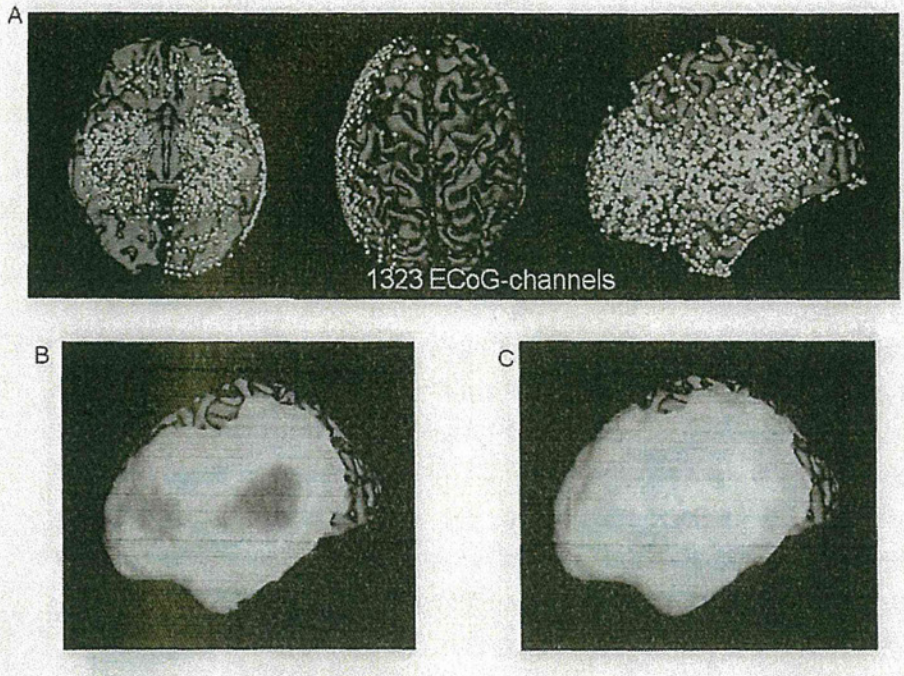

Fig.4 (A) Normalization of 12 brains with 1323 ECoG electrodes.Density correction making gradation of ECoG electrodes (B) uniform (C) .

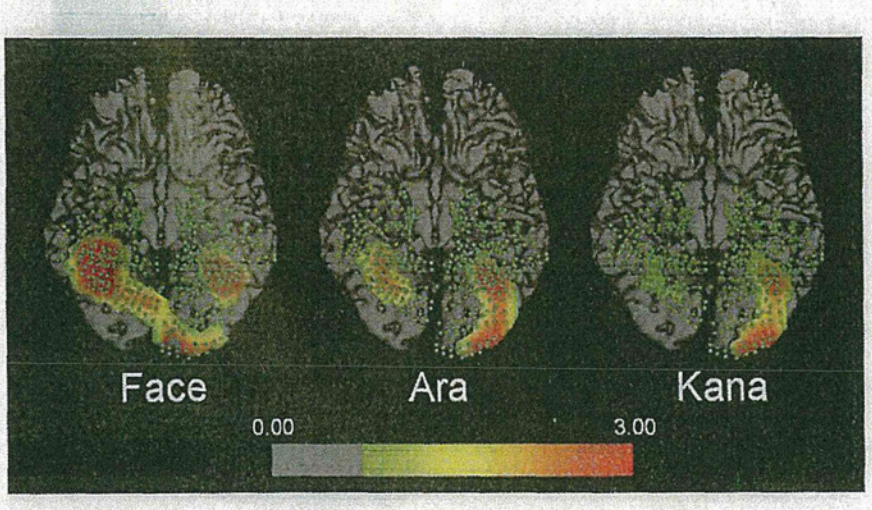

Fig.5 Typical distribution of Gamma band components related to visual stimuli on the standard brain.Face stimuli activated the bilateral temporal base including inferior temporal and fusiform gyri with right hemispheric dominancy.Kana stimuli evoked Gamma band components only in the left fusiform and parahipocampal gyri.

測した。さらにECoGの加算平均、時間－周波数解析結果を患者毎脳表に投射するソフトウエアを作成した。側頭葉底部では視覚刺激が単純であればあるほど、後頭極側にγ帯域成分が局在する傾向があった。一方複雑な刺激になると反応する領域が広がっていた。顔刺激では右優位であり、かつ両側側頭葉底部の前外側に活動が強くなっていた。物品名称・記憶課題関連ECoGの加算平均では、記憶課題の時に600msecほどの潜時に陽性－陰性波を認めた。さらに時間－周波数解析では、記憶課題時に内側側頭葉に刺激提示後500-600msecに80-120Hzのγ帯域成分が有意に上昇していた。このγ帯域成分の上昇のある内側側頭葉に手術を行った4例全例で記銘力障害が出現し、上昇のない側の手術をした4例では記銘力を含む高次脳機能障害の出現はなかった。記憶課題により誘発された内側側頭葉のγ帯域成分は記憶機能と密接に関連しているものと考えられた。電極位置の標準化は視覚刺激による側頭葉底部の典型的な反応パターンを可視化することを可能とした。文字認知では左紡錘状回－海馬傍回に、顔認知では右紡錘状回から下側頭回にγ帯域成分が出現していた。

近年頭蓋内電極によるγ帯域成分の変化に着目した報告が散見される。これらの検討では主に運動、文字読みなどに関連したγ帯域成分のダイナミクスに着目している。特に文字読み課題では文字提示後約500msec後に左下前頭回、運動野近傍にγ帯域成分の増加を認めるとされている。Sinaiらは脳皮質電気刺激マッピングで抑制される言語関連機能とγ帯域成分局在を検討し、その局在感度は84％と高いことを報告している[4]。しかし、側頭葉底面、および内側側頭葉領域のγ帯域成分ダイナミクスに関する検討は未だ十分に行われていない。

海馬を中心とした内側側頭葉の活動に関しては、HalgrenらがP300由来の電位変化を頭蓋内電極を用いて海馬から検出した[5]。しかし、海馬周辺から得られた電位変化と脳機能との関連に関しては言及していない。その後の誘発電位の研究では内側側頭葉前部でのN400、海馬でのP600が認識記憶に関連しているとされているとの報告もある[6]。本検討では記憶課題に伴い誘発されたγ帯域成分の局在と手術による機能変化を比較することで、記憶機能を正確に電位変化として捉えることができた。記憶機能の側方性は極めて重要であるにも関わらず、Wada testによる記憶機能検査を参考としているのが現状であった。本検査法、およびその結果は記憶機能の局在、ダイナミクスを解明する上でも極めて重要である。

頭蓋内電極は画像診断、臨床症候に基づいて、その留置位置と範囲が決定される。診断的目的で電極が留置されるために、患者毎にその留置範囲が異なることが脳機能解析面における課題であった。本報告ではSPM8を用いて頭蓋内電極位置を標準脳上に変換することで、高密度の電極分布による解像度の高いECoG解析を可能とした。本方法により異なる視覚刺激による側頭葉底面の誘発電位パターンを明らかにすることができた。SPM8による“標準化”はfunctional MRIを始め、Diffusion tensor imaging, 脳血流シンチグラムなどに応用され、アルツハイマー病、脳虚血疾患診断

に応用されてきた[7,8]。しかし、ECoGを標準化し、高い空間解像度、および時間分解能で典型的な電気的活動の表示を可能としたのは本報告がはじめてである。特に顔認知では右側優位、かつ紡錘状回外側、および下側頭回にγ帯域成分の広がりが特徴的であった。側頭葉底部の機能分布に関する検討は functional MRI で行われている。Puri らのは側頭葉底部外側は顔認知で強く活動する Fusiform Face Area (FFA)、さらに内側部は物品認知などに関連する Parahipocampal Place Area (PPA) と分類している[9]。我々の検討では FFA と PPA の局在を電気生理学的に検証することができた。今後本方法を用いることにより電気的活動の空間的広がりに加え、周波数帯域別の変化およびそれぞれの時間的ダイナミクスをより詳細に解明することができる。頭蓋内電極を用いた脳機能マッピングは現在のところ脳皮質電気刺激法が Gold-standard である。しかし、この電気刺激法では刺激強度、時間の制限、けいれん発作誘発のリスクを伴うため、できる限り刺激頻度を減らし、検査時間を短時間にすることが最も患者の負担軽減につながる。本研究で施行した認知課題誘発 ECoG の計測、データ処理、画像化は今後脳皮質電気刺激法の代替法となり得る。また、内側側頭葉活動を捉えることで記憶機能の評価に応用できる可能性もある。さらに標準化 ECoG 法により、ヒト脳機能ダイナミクスを詳細に検討することができ神経科学への貢献も期待できる。

文　献

1. Wiebe S, Blume WT, Girvin JP, Eliasziw M.A randomized, controlled trial of surgery for temporal-lobe epilepsy.N Engl J Med.2001 Aug 2;345 (5) :311-8.
2. Englot DJ, Chang EF, Auguste KI.Efficacy of vagus nerve stimulation for epilepsy by patient age, epilepsy duration, and seizure type.Neurosurg Clin N Am.2011 Oct;22 (4) :443-8, v.
3. Kim DW, Kim HK, Lee SK, Chu K, Chung CK.Extent of neocortical resection and surgical outcome of epilepsy: intracranial EEG analysis.Epilepsia.2010 Jun;51 (6) :1010-7.
4. Sinai A, Bowers CW, Crainiceanu CM, Boatman D, Gordon B, Lesser RP, et al.Electrocorticographic high gamma activity versus electrical cortical stimulation mapping of naming.Brain.2005 Jul;128 (Pt 7) :1556-70.
5. Halgren E, Squires NK, Wilson CL, Rohrbaugh JW, Babb TL, Crandall PH.Endogenous potentials generated in the human hippocampal formation and amygdala by infrequent events. Science.1980 Nov 14;210 (4471) :803-5.
6. Klaver P, Fell J, Dietl T, Schur S, Schaller C, Elger CE, et al.Word imageability affects the hippocampus in recognition memory. Hippocampus.2005;15 (6) :704-12.
7. Kunimatsu A, Aoki S, Masutani Y, Abe O, Mori H, Ohtomo K.Three-dimensional white matter tractography

by diffusion tensor imaging in ischaemic stroke involving the corticospinal tract. Neuroradiology.2003 Aug;45 (8) :532-5.
8. Schuitemaker A, van Berckel BN, Kropholler MA, Veltman DJ, Scheltens P, Jonker C, et al.SPM analysis of parametric (R) -[11C]PK11195 binding images: plasma input versus reference tissue parametric methods. Neuroimage.2007 May 1;35 (4) :1473-9.
9. Puri AM, Wojciulik E, Ranganath C.Category expectation modulates baseline and stimulus-evoked activity in human inferotemporal cortex.Brain Res.2009 Dec 8;1301:89-99.

Abstract

Localization Analysis of Cognitive Functional Regions by Electrocorticogram

Kyousuke Kamada, Masao Sato

Department of Neurosurgery, Asahikawa Medical University

Kyousuke Kamada M.D., Department of Neurosurgery, School of Medicine, Asahikawa Medical University / 2-1, Midorigaoka-Higashi, Asahikawa, Hokkaido, 078-8510, JAPAN

For careful interpretation of spatial and temporal changes of electrocorticogram (ECoG) with semantic tasks, we developed a software to visualize semantic-ECoG dynamics on individual brain.Twenty patients underwent implantation of subdural electrodes for diagnostic purpose.Semantic-ECoG was recorded with word, figure and face recognition and memory tasks.The ECoG raw data was processed by ime-frequency analysis and the functional profiles were projected on individual brain surface.Because of variations of electrode locations, we normalized the ECoG elecrtodes using SPM8.The basal temporal-occipital cortex was activated within 250 msec after visual object presentations.Face stimulation evoked significantly higher ECoG amplitudes than other stimuli.The hipocumpus was dominantly activated than other brain areas by the memory task.Prediction rate od ECoG-classification reached 90 % , which was sufficient for clinical use. Semantic-ECoG is a powerful

technique to detect and decode the human brain functions.

Key words: Electrocorticogram, Epilepsy, Language, Memory, Visual stimulation

脳卒中の外科 40: 317～321, 2012

原　著

脳神経外科診療の実績作りに脳血管内治療医は貢献しているか？

和田　始[1]，櫻井　寿郎[2]，上森　元気[1]
折本　亮介[1]，広島　覚[1]，三井　宣幸[1]
佐藤　正夫[1]，安栄　良悟[1]，鎌田　恭輔[1]

Contribution of the Neuro-endovascular Physicians to Improvement in Neurosurgical Operations

Hajime WADA, M.D.,[1] Jyurou SAKURAI, M.D.,[2] Genki UEMORI, M.D.,[1] Ryousuke ORIMOTO, M.D.,[1] Satoru HIROSHIMA, M.D.,[1] Nobuyuki MITSUI, M.D.,[1] Masao SATOU, M.D.,[1] Ryougo ANNEI, M.D.,[1] and Kyousuke KAMADA, M.D.[1]

[1]Depratment of Neurosurgery, Asahikawa Medical University, and [2]Department of Neurosurgery, Moriyama Hospital, Asahikawa, Hokkaido, Japan

Summary: The last 10 years, neuro-endovascular treatment has been widely accepted and is becoming more popular, both because devices have become more developed and because the treatment is supported by evidence.

Our neurosurgical department at Asahikawa Medical University Hospital exists in a city with a population of 360,000. Although the department has had two physicians with Japanese neuro-endovascular board certification for 10 years, both of them were absent for two years (between 2007 and 2009).

We divided a recent 10-year period into two periods: when the endovascular physicians were present and when they were not to investigate clinical activities and practical operations such as the number of treatments, surgical time and number of admissions.

The total number of operations was 1,871. The period when the neuro-endovascular physicians were there (60 months) had 916 cases, and the other periods (78 months) had 955 cases. The number of cases of neuro-endovascular treatment was 145 and 41, respectively. During the period with the physicians, not only the total number of endovascular treatments, but also the average monthly case volume of all neurosurgical operations increased significantly. The surgical time for cerebral aneurysm and cervical carotid stenosis was significantly shorter with endovascular treatment than open surgery.

The existence of neuro-endovascular physicians increases the efficiency of neurosurgical treatment and stimulates department activity.

Key words:
- neuro-endovascular treatment
- neurosurgery
- department management

Surg Cereb Stroke (Jpn) 40: 317-321, 2012

[1]旭川医科大学　脳神経外科，[2]森山病院　脳神経外科（受稿日 2011.12.20）（脱稿日 2012.3.23）〔連絡先：〒078-8510 北海道旭川市緑ヶ丘東2条1丁目1-1 旭川医科大学 脳神経外科　和田　始〕[Address correspondence: Hajime WADA, M.D., Department of Neurosurgery, Asahikawa Medical University, 2-1 1-1 Midorigaokahigashi, Asahikawa, Hokkaido 780-8510, Japan]

Table 1 Numbers of cases per month with and without endovascular physician

	Endovascular physician (−)	Endovascular physician (+)	p
Total endovascular treatments	0.52 ± 0.75	2.41 ± 1.54	p<0.0001
Clipping	1.10 ± 0.95	0.95 ± 0.89	p=0.338
Clipping and coil	1.14 ± 0.95	1.98 ± 1.20	p<0.0001
Total neurosurgical operations	12.2 ± 3.9	15.3 ± 3.9	p<0.0001
Total neurosurgical admission patients	784.6 ± 111.9	782.6 ± 141.7	p=0.463

(Numbers of cases/month, Student t)

はじめに

脳血管内治療は，1997年に脳動脈瘤用のGuglielmi detachable coil (GDC)が保険収載となり本格的に日本に導入された．その後徐々にdeviceの進歩，evidenceの獲得に伴い，この領域の地位を確立するとともに広く普及した．当施設でも2001年から2名が臨床海外留学．その後日本脳神経血管内治療学会専門医取得プロトコールにのっとり研修，専門医取得を終え脳神経外科診療に血管内治療医が加わった．しかし現在まで，諸般の事情により常勤医としてチーム診療ができなかった時期があった．

そこで，人口36万人の小都市にある大学附属病院の10年間で，血管内治療医がいた時期といなかった時期で，診療科としてのactivityを比較するため脳血管内治療数，脳神経外科全体の手術件数，入院患者数を検討した．さらに代表的な治療対象である脳動脈瘤の治療数，その内訳を在籍した時期，しない時期4つに分け検討した．

対　象

対象期間は，2000年1月から2011年6月までの138か月間において血管内治療医在籍時不在籍時で比較した．さらにこの間を当初の不在時期と，当医局員2人がフランスロスチャイルド病院脳血管内治療臨床留学から帰国し，1例目の頚部内頚動脈ステント留置術(carotid artery stenting: 以下CAS)を行った2004年1月～2007年9月を在籍時期とし，その後2名とも退職した期間2007年10月～2010年3月を経て，脳神経血管内治療学会専門医が復職した2010年4月以降の4つの時期に分け検討した．当施設内に血管内治療医が不在時にも，関連施設の脳血管内専門医を招聘し，脳血管内治療は行われていた．2群間の比較に，Student t検定．多群間の検定にsingle-factor ANOVAによる統計学的解析を行った．

結　果

血管内治療医の不在，在籍時の比較

この期間の総手術数は1,871件，脳血管内治療医在籍時916件，不在時955件．脳血管内治療数は血管内治療医在籍時145例，不在時41例であった．脳血管内治療医不在時，在籍時に分け脳血管内治療数，クリッピング数，クリッピングとコイル塞栓術数を合わせた脳動脈瘤治療数，脳神経外科の全手術数，脳神経外科の入院患者数を比較した(**Table 1**)．脳血管内治療医在籍時に，脳血管内治療数が多かった(血管内専門医不在時期0.52 ± 0.75/月，在籍時期2.41 ± 1.54/月，P<0.0001，Student t検定)．また，この2つの時期でクリッピング術数に有意差は認めなかったが(血管内専門医不在時期1.10 ± 0.95/月，在籍時期0.95 ± 0.89/月，P=0.338，Student t検定)，クリッピングとコイル塞栓術を合わせた脳動脈瘤治療数は脳血管内治療医在籍時に多かった(血管内専門医不在時期1.14 ± 0.95/月，在籍時期1.98 ± 1.20/月，P<0.0001，Student t検定)．同様に脳神経外科の全手術数も両群間に有意差を認めたが(血管内専門医不在時期12.2 ± 3.9/月，在籍時期15.3 ± 3.9/月，P<0.0001，Student t検定)，全脳神経外科入院患者数には有意差を認めなかった(血管内専門医不在時期784.6 ± 111.9/月，在籍時期782.6 ± 141.7/月，P=0.463，Student t検定)．

脳血管内治療の内訳

脳血管内治療の種類による内訳は**Fig. 1**．不在時には動脈瘤コイル治療の割合は低いが，thrombolysis，動静脈瘻(arteriovenous fistula: 以下AVF)，腫瘍の塞栓術などopen surgeryで補えない治療分野の割合が大きくなっていた．

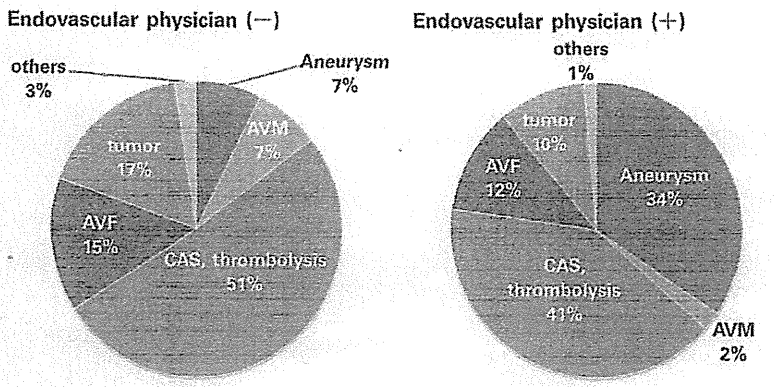

Fig. 1 Types of endovascular treatment with and without endovascular physician.

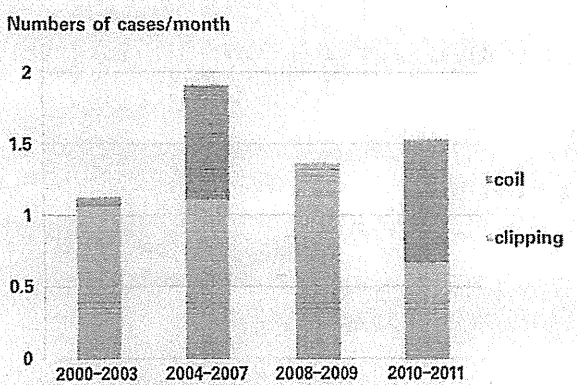

Fig. 2 Number of operations for cerebral aneurysms per month (The period 2004–2007 and 2010–2011 are with endovascular physician).

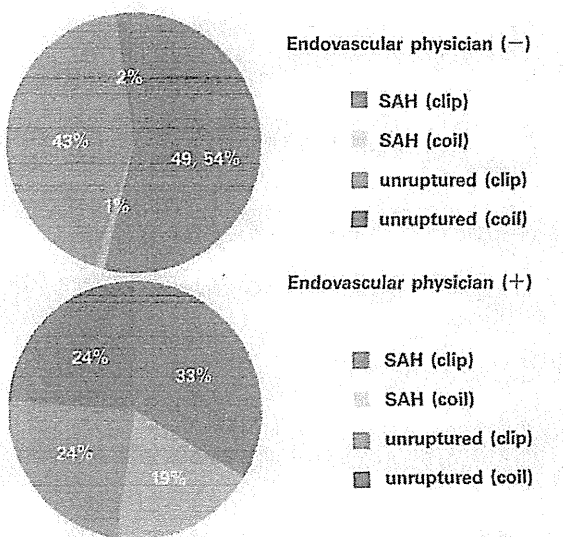

Fig. 3 Number of operation for ruptured and unruptured aneurysms.

動脈瘤治療の検討

当科におけるクリッピングコイル両治療法合わせた全動脈瘤治療の推移を血管内治療医の有無により4つの期間に分け検討した(**Fig. 2**). 期間ごとの症例数に上下の波があった(P=0.0016, single-factor ANOVA). 2004年から2007年の時期だけ有意に多かった理由は不明だが, 全脳動脈瘤治療数はTable 1で示したように血管内治療医が勤務していた時期に多かった.

脳動脈瘤治療を破裂, 未破裂動脈瘤で比較すると, 血管内治療医の有無にかかわらず, 両者の割合に変わりはなかった(**Fig. 3**).

動脈瘤の部位の分布については2群間で変わりはなかった. 不在時には内頚動脈と, 後方循環に限定されて血管内治療が行われていた. しかし, 在籍時には前交通動脈瘤などにも脳血管内治療が適応されていた(**Fig. 4**).

治療時間の比較

治療時間の比較. 平均治療時間は脳動脈瘤コイル塞栓術で2.29±0.76時間, CASで1.64±0.64時間, clippingは7.97±2.39時間, 内頚動脈内膜剝離術(carotid endarterectomy: 以下CEA)では5.03±1.43時間であった. 頚部内頚動脈狭窄症, 脳動脈瘤治療とも脳血管内治療時間の方が短かった(ともにP<0.0001, Student t検定) (**Table 2**).

考　察

ISAT studyは, 破裂動脈瘤治療におけるcoil治療の有用性を証明した[8]. 日本でもこれらevidenceを受けて, メディアなどで取り上げられることも追い風となりcoil治療