

# MEGvision MAGNETOENCEPHALOGRAPH SYSTEM AND ITS APPLICATIONS

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*The magnetoencephalograph (MEG) is a measurement instrument specifically designed to measure electrophysiological cerebral nerve activities, featuring high time and spatial resolution performance. In recent years, the evolution of the SQUID (Superconducting Quantum Interference Device) magnetic sensor utilizing superconductor technology has enabled the consistent measurement of extremely weak magnetic fields generated by the brain, and the clinical availability of MEG has been established by clinical studies based on the accumulation of MEG data, thereby resulting in the clinical application of MEG in general hospitals beyond laboratory tests. Our “MEGvision” 160-channel whole-head MEG system was released in 1998, and approved by the Japanese Pharmaceutical Affairs Law in 2000. Since then, a total of seven systems: three systems for general hospitals, two systems for the medical departments of universities, two systems for the engineering or humanities departments of universities, have been in use so far. Owing to the governmental approval of healthcare coverage for MEG examinations in April 2004, the further utilization of MEG is expected. This paper describes the technical features of MEG and examples of its application.*

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## INTRODUCTION

The activity of nerve cells is a kind of ion current. A current flowing in association with the excitatory postsynaptic potential (EPSP) of cone cells present in the brain cortex generates an extremely weak magnetic field in its surrounding. In recent years, the magnetoencephalograph (MEG)<sup>(1)</sup> which can detect this field has rapidly developed, and as a result, has attracted interest in a wider area, ranging from the field of basic research such as brain science to clinical examinations in general hospitals (Figure 1). As our society becomes increasingly aged

and central nervous diseases including dementia are becoming an important issue, there are high hopes on the MEG as an effective technique for diagnosing brain functions. The MEG, directly capturing electrical activity rather than secondary phenomena such as increases or decreases in metabolism or a vascular flow caused by nervous activity, has high time resolution (on the order of ms) and high spatial resolution (on the order of mm). It can be called the “third modality” which is different from conventionally available brain diagnostic equipment such as the MRI and CT which obtain anatomical or morphological images, or the PET and SPECT capable of converting oxygen or glucose metabolism into images (Figure 2). Moreover, the MEG is non-invasive equipment that passively detects magnetic fields generated from the patient without imparting an external magnetic field or emitting X rays, radiation rays, etc.

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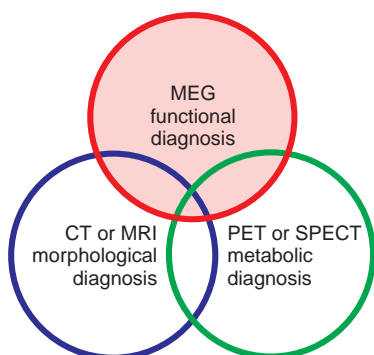
**Figure 1** MEGvision Magnetoencephalograph System

## FEATURES OF THE MEGVISION MAGNETOENCEPHALOGRAPH

The intensity of the magnetic field generated by the brain is as little as several tens of fT (femto Tesla:  $10^{-15}$  Tesla); MEGvision was able to consistently measure it using the SQUID (high-sensitivity superconducting quantum interference device) magnetic sensors that make use of superconductivity. Yokogawa Electric started to develop the SQUID fluxmeter in 1974, and succeeded in measuring the biological magnetic field generated by the heart for the first time in Japan, in 1976. Successive efforts in research and development bore fruit and Yokogawa released the “MEGvision” 160-channel whole-head MEG system in 1998,

which was approved as medical equipment by the Japanese Pharmaceutical Affairs Law<sup>(1)</sup> in 2000.

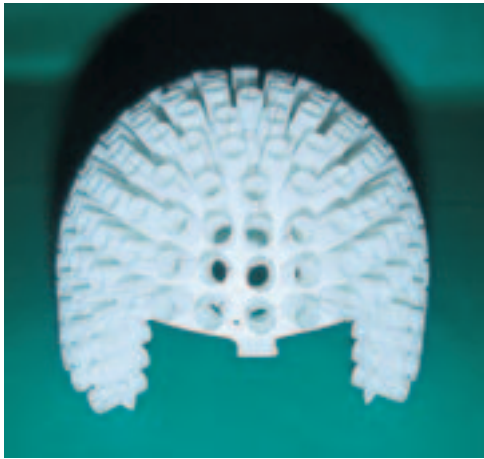
The key technology of the MEG is the SQUID fluxmeters which detect the extremely weak magnetic field generated by the brain (Figure 3). A SQUID fluxmeter consists of a pickup coil and SQUID, and the pickup coil can be compared to an antenna collecting magnetic fields. Putting some thought into the shape of the pickup coil has enabled the signal detection and noise immunity characteristics to be adjusted. MEGvision has adopted a coaxial gradiometer that is superior in eliminating external noise and provides little attenuation of signals from the brain. Since its baseline is as long as 50 mm, the gradiometer can detect signals from deeper regions of the brain. The SQUID, which converts magnetic fields into electric signals, adopted a construction less influenced by external noise, resulting in the achievement of a magnetic field resolution of  $3 \text{ fT}/\sqrt{\text{Hz}}$  (typical)



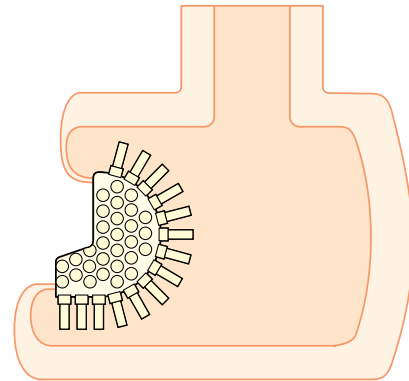
**Figure 2** Comparison of Modalities



**Figure 3** SQUID Fluxmeter



**Figure 4** Arrangement of the Magnetic Sensors



**Figure 5** Horizontal Dewar construction

for the entire equipment. This is the top performance in the industry. In this way, a combination of the high-performance pickup coil and low noise level SQUID has enabled a wider range of objects to be able to be examined by the MEG.

MEGvision places the SQUID fluxmeters at 160 locations to cover the entire head, so that the complex magnetic field source generated by the activity of the brain can be recorded at a high spatial resolution (Figure 4). Furthermore, working on the premise that it is to be used in hospitals, it was the first in the world to achieve the complete, horizontal dewar construction that puts no burden on the patient (Figure 5).

## APPLICATION FIELDS OF MEG

The feature of MEG is that the functional information of the central nerves can be obtained. Obtainment of functional information is to identify the regions of functions localized at brain cortex levels such as the motor area, somatic sensory area, visual area, auditory area, and speech area, to examine the transition of active regions capitalizing on the excellence of the time resolution (on the order of ms level), and to quantify the degree of the nerve activity based on the intensity of the detected signal, i.e., the intensity of a current of active nerve cells.

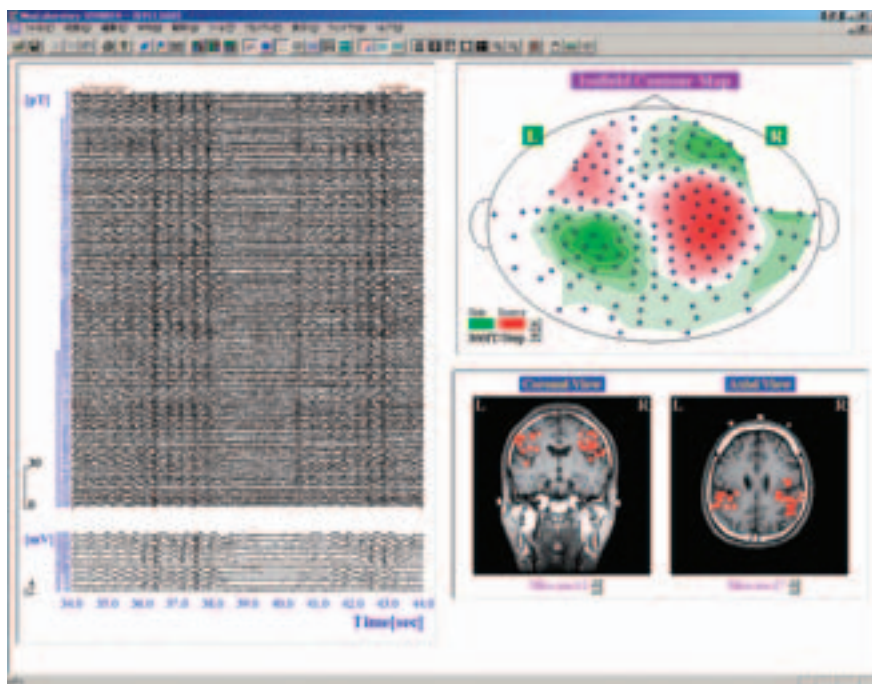
The diagnostic methods that have already been established as forms of clinical examinations include the identification of function regions made prior to neurosurgery and the identification of focal areas of focal symptomatic epilepsy. If the functional region localization allows the functional map of a brain to be known, it can be reflected in the surgery plan so that no function is damaged by neurosurgical procedures. That is, no after-effects or complications are caused. For the localization of focal epilepsy, combining the MEG with other image diagnostic equipment allows an intracranial electrode-based electroencephalogram, which is burdensome to the patient, to be skipped in some cases. This has led to the recognition of improvements in the patient's quality of life (QOL) and medical, economical effectiveness.

The diagnostic technologies at clinical study levels include the localization of language dominant hemisphere, quantitative diagnoses of cortical function degradation, prediction of surgery results, diagnosis of differentials in epilepsy types, and diagnoses of the plasticity of brain functions. The evaluation of brain functions is also regarded as important from the viewpoint of involvement with rehabilitation. Moreover, research has been conducted to diagnose psychiatric illnesses such as schizophrenia, on the basis of differences in responses to allopsychic stimuli.

In the field of basic research, MEG has been used for research on the high-degree brain functions specific to humans, such as language and recognition processes, or research on the physiological mechanisms of sensory functions and motor functions such as visual or auditory senses. Because MEG is a non-invasive technique, it can also be applied safely to able-bodied people.

The illnesses examinable in clinical applications by MEG are general central nervous system illnesses such as epilepsy or brain tumors, and sensory-function or motor-function damage associated with central nerve illnesses. If we consider research applications, the range of illnesses covers cerebrovascular illnesses, head injuries (after-effects and complications), spinal disorders, peripheral nerve disorders, Parkinson's Disease, Alzheimer's Disease, schizophrenic neurogenous diseases, higher-level brain damage, developmental brain disorders, and sensory disorders such as hearing impairment and visual disorders. An attempt has been made to use MEG in the diagnoses or early detection of dementia or the determination of pharmaceutical effects.

As an example of a clinical application, a case of both-side cortical alloplasia is shown in Figure 6. Cortical alloplasia is a congenital malformation of the brain cortex and often results in profound epilepsy. The upper left diagram shows magnetoencephalogram displayed as waveform, while the lower left one shows the brain waves recorded at the same time. The



**Figure 6** Clinical Application (Diagnosis of an Epileptic Focus Area)

upper right image shows the equivalent magnetic field diagram at a specific time, while the lower right one shows an image in which a focal area estimated from magnetoencephalogram of a paroxysmal intermission was superimposed on MRI. We recognized that current dipoles were integrated in the bilateral parietooccipital regions and agreed with a cortical allopasia area. This example indicates that magnetoencephalogram examination is useful for estimating an epileptic focus.

## INVOLVEMENT WITH INFORMATION TECHNOLOGIES

In analyses of magnetoencephalogram, images are utilized in which information about the activity regions of nerves and time course of the nerve activity obtained from MEG has been superimposed on a morphological image of MRI, CT, etc. Alternatively, there are cases where the results obtained by diagnosing magnetoencephalogram are sent to a surgical navigation system to reflect them in a surgical plan or utilize them in surgical support. Requirements for MEG are to link MEG with a picture archiving and communications system (PACS) to exchange image data, rather than operating it independently. The magnetoencephalogram has not yet been specified in the DICOM (digital imaging and communications in medicine) Standards. Further progress is expected and possible future standardization would benefit for MEG diagnosis significantly.

On the other hand, the magnetoencephalogram also has aspects of an electrophysiological examination. One approach is to record magnetoencephalogram simultaneously with electroencephalograph (EEG) to capture nervous activity from

both the magnetic and electrical viewpoints to improve the accuracy of the examination. This approach is especially essential in epileptic examination. Both methods measure the same electrophysiological phenomenon, but there are differences in measurement results between magnetoencephalogram and electroencephalograph; there are cases where the nervous activities detectable by not EEG but only MEG, or alternatively by not MEG but only EEG are captured. Therefore, to avoid failing to capture those nervous activities, in clinical applications, a comprehensive system integrating magnetoencephalogram and electroencephalograph becomes important.

## MEG GUIDELINES AND INSURANCE COVERAGE

The Japanese Society of Clinical Neurophysiology (JSCN) established the Committee on Preparation of Guidelines for Clinical Applications of MEG in 2003. JSCN has the achievement of summarizing the electrophysiological examination guidelines for brain waves. Thanks to this committee, the examination procedures for magnetoencephalograms, which varied from facility to facility, have been being summarized and standardized, and a tentative plan has been released<sup>(2)</sup>. The guidelines aim to achieve certain diagnostic results without the help of a specially trained person. This is necessary in order for the MEG to transition from being a tool for some researchers to being clinical examination equipment that is widely used in general hospitals.

Also, in Europe, the International Workshop on MEG was held in Germany in 2003, and the participants have prepared a consensus draft of MEG examinations for epilepsy diagnoses. The final objective is to get approval for the draft from the

International League Against Epilepsy (ILAE) committee and to publish it in the scientific journal "Epilepsia."

In Japan, MEG examination has been approved as "neural magnetic diagnosis" in Highly Advanced Medical Care since 1994 and was conducted in nine facilities. Moreover, it has been reimbursable (at 5000 points) by insurance since April 2004. The situation has made progress from one in which a patient could only have a MEG examination by bearing high costs in medical care at him/her discretion or Highly Advanced Medical Care. This is good news for patients. Also, as MEG examinations now qualify for reimbursement from insurance, the medical personnel concerned are beginning to show an increasing interest in it.

In the USA, more than 1000 cases of MEG examinations were reimbursed by more than 250 insurance companies or public organizations up to the year 2001. Furthermore, the American Medical Association issued the Current Procedural Terminology (CPT) codes for MEG examinations on January 1, 2002.

## CONCLUSION

MEG is beginning to be evaluated as a new modality in clinical sites, but its analytical or diagnostic technologies are said to be still in the developmental stage. Thus, the evolution of analytical technologies, primarily in software, has been desired.

Although it is assumed that the MEG will attract keen interest from general hospitals as MEG examinations are covered by insurance, there are also calls for the development of peripheral supporting technologies because of problems such as maintenance costs related to its operation and coordination with in-hospital information systems.

We, at Yokogawa, work toward technological developments with the aim of achieving further development and progress, and intend to be the foundation of neurological research and medical advances. ◆

## REFERENCES

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\* MEGvision is a registered trademark of Yokogawa Electric Corporation and CPT is a registered trademark of the American Medical Association.

