

Significance of MEG in Presurgical Epilepsy Evaluation

Summary

Magnetoencephalography (MEG), as a non-invasive procedure, records magnetic fields generated by spontaneous or evoked brain activity. Presurgical evaluation of pharmacoresistant patients with focal epilepsy is currently the most frequent diagnostic application. The source of epileptic or averaged evoked activity is localised and then overlaid onto magnetic resonance imaging (MRI) of the patient's brain. For source localisation advanced techniques use information extracted from the individual brain. The localisation results can guide invasive recordings and help in neurosurgical operation planning. Owing to the physical constraints of MEG and EEG, source localisation can be improved by simultaneous recording. Together with other diagnostic methods, MEG plays an important role for focus localisation in patients with intractable epilepsy.

MEG recording by distant electromagnetic noise. The acquired data describe the change of the magnetic fields. In contrast to electric fields, magnetic fields are less distorted by the resistive properties of the skull and scalp. Electric and magnetic fields are oriented perpendicular, orientation of the highest sensitivity for EEG and MEG is orthogonal to each other. Therefore both non-invasive methods are complementary, the combination of both techniques yields information not available from either technique alone.³

Source localisation

The so-called neuromagnetic 'inverse problem' - the tracing of an unknown source in the brain from magnetic field data recorded outside the head - has no unique solution, additional constraints are necessary. An algorithm iteratively minimises the differences between the observed and the calculated field for a hypothetical source. For an estimated dipolar source, the magnetic fields in the sensors or the electric potential at the scalp can only be calculated, when the electromagnetic properties of the volume between are known. This description of the head's properties is called volume conductor, which is commonly based on individual anatomical structures. A volume conductor model, which resembles the electromagnetic properties of the head, is more difficult to obtain for EEG than for MEG.⁴ This is because inhomogeneities in conductivity hardly affect magnetic fields, but they considerably alter the way an electrical potential within the brain is transformed to the head surface.⁵ The first and still widely used head model is a homogeneous and isotropic spherical head model. Boundary element methods can describe the surfaces of volumes with identical electromagnetic properties in the individual MRI.³ The goal is to estimate the individual features as closely as possible, since any deviation between the actual and the assumed volume conductor might influence the results.⁶

The configuration of the source signal can also be approximated by a model. The single equivalent current dipole model has been used most frequently. However, when sources overlap both spatially and temporally (ie. in the case of multifocal sources) the approach of a multidipole source model might be more appropriate.⁷ Furthermore, current density reconstruction methods without assumptions about the source signal are applied. This method searches for the minimum currents which can explain the measured field; they have been preferentially applied for a more extended generator.⁸ All localisation results have to be understood as the centre of a confidence volume.

Introduction

In the last decade diagnostic techniques have improved and by so doing have allowed for a more individually tailored epilepsy surgery, such that it has gained importance for patients with intractable epilepsy. The aim of presurgical evaluation is to identify the epileptogenic zone which is necessary and sufficient to control seizures when removed.^{1,2} For this purpose, several diagnostic methods are applied: Electroencephalography (EEG), Magnetic Resonance Imaging (MRI), Positron-Emission-Tomography, Single-Photon-Emissions Tomography, Video-EEG-Monitoring, neuropsychological investigation and Magnetoencephalography (MEG). Among these methods, the significance of MEG is based on a high temporal and good spatial resolution which in turn allows for identification of functionally important areas relative to the epileptogenic region.

Data acquisition

MEG and EEG measure the electromagnetic signals of the brain, which are generated by the activity of cortical neurons. The magnetic field of the brain is extremely weak (10^{-12} to 10^{-15} Tesla) and thus much smaller than the ambient electromagnetic noise in the environment. The development of a superconducting quantum inference device (SQUID) allows the investigation of the brain's magnetic activity. A shielded room attenuates disturbance of the



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Michael Fischer studied medicine at the University of Erlangen-Nuremberg. The research year in the MEG laboratory addressed the differences between source localisations in MEG versus EEG and the effect of different volume conductors. A further project deals with the generation of result volumes from single source localisations. The current research interest is focused on pain.



Hermann Stefan is Neurologist and Epileptologist. In his position as director of the Epilepsy Center at the Neurological Department of the University Clinic Erlangen, Germany, his work is concentrated on the investigation of epilepsies, their diagnostics, differential typology and therapeutic treatment. For this purpose he increased the diagnostic possibilities of clinical application and subsequently specialised in the preoperative diagnosis in patients with therapy resistant epilepsies.

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Figure 1a: Whole head system, VSM MedTech Ltd, Coquitlam, BC, Canada.



Figure 1b: Whole head system, 4D-Neuroimaging, San Diego, California, USA.

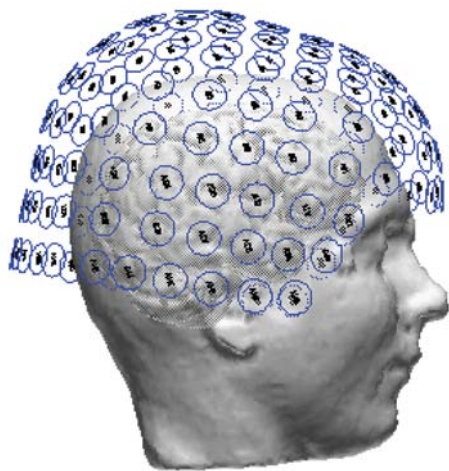


Figure 2: Sensorpositions of a 148-channel MEG-whole head system Magnes 2500 WH, visualised over a surface reconstruction of head and brain of a patient. Sensorposition data are courtesy of Prof Dr Angela D Friederici, MPI for Neuropsychology, Leipzig, Germany.

After coregistration of MEG and MRI data using a combined coordinate system, localisation results can be superimposed to individual brain anatomy (Magnetic Source Imaging, MSI). Source localisation of epileptic discharges can thus be attributed to specific brain structures.

Diagnostic yield

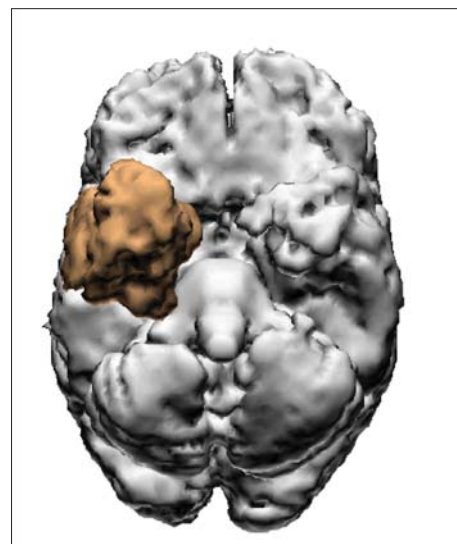
Magnetoencephalography (MEG) can contribute to the presurgical evaluation process. In a retrospective study interictal spikes were detected in 76% of 300 patients, the epileptic lobe was correctly identified in 89% of 455 cases and MEG yielded crucial information for decision making in 10% of these patients.⁹ The contribution of MEG to the general result of presurgical evaluation was quantified in 104 patients. MEG supplied additional information in 35% and information crucial for the final decision in 10%. In a systematic study of 58 patients MEG performed better than both interictal (33%) and ictal (20%) scalp-EEG, but worse than interictal (75%) and ictal (81%) intracranial EEG.¹⁰ MSI has also been found to offer useful source locations of cryptogenic epileptic activity in accordance with other non-invasive results. In 11 out of 12 patients without focal abnormality in MRI, MEG discharges were localised to the epileptogenic zone as determined by standard preoperative evaluation.¹¹ A good positive outcome was correlated with a high coverage of MEG results by the neurosurgical resection.¹² Review of MEG-localised epileptiform areas on high-spatial-resolution MR images can enable detection of epileptogenic neocortical lesions, some of which are occult on conventional MR images.¹³

In cases where neurosurgery remains the only therapeutic hope for epileptic patients, it is essential that not only the site of the epileptogenic region is known, but also to determine whether removal of the tissue in question may cause functional deficits. The localisation of primary sensory and essential secondary cortical areas are required to design neurosurgical strategies. Structural imaging fails to reliably



Figure 3: Patient with polymicrogyria in right temporal lobe. Outcome after resection: patient is seizure free.

Figure 3a: MEG localisation of the epileptiform focus (white). Figure 3b: Segmentation of the resected part of the brain (black).



identify functionally significant areas which may be displaced not only by tumors or oedema, but also by brain plasticity. However, MEG localisations of the primary somatosensory, auditory and visual cortices are performed routinely and have been used for preoperative planning as well as intraoperative neuronavigation.¹⁴ Functional MEG localisations are particularly favourable in cases where the epileptogenic area is closely related to overlapping, eloquent regions.

The applications of MSI in presurgical epilepsy evaluation can be summarised as follows:

- Localisation of focal epileptic activity to guide invasive procedures and thus reduce invasive regimens
- Delineation of functionally significant areas (which must be spared in neurosurgery) by means of evoked activity
- Localisation of focal epileptic activity to guide detailed planning of neurosurgical procedures, eg. with neuronavigation, aiming at the removal of as little tissue as possible.

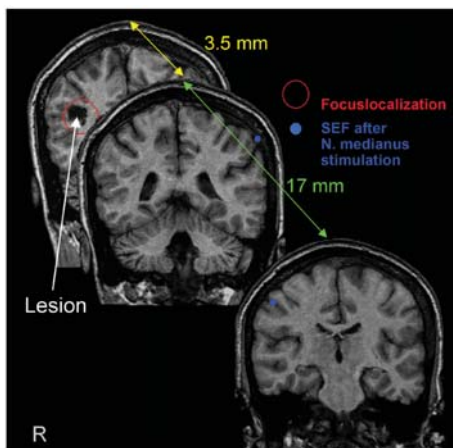


Figure 4: MEG localisation result at the border of the lesion (red). Somatosensory evoked fields (SEF) after medianus stimulation. Reorganisation of the somatosensory representation on the side of a lesion in a frontal direction in a patient with symptomatic extratemporal epilepsy.

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