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INFLUENCE OF SKULL DEFECTS ON MEG SOURCE RECONSTRUCTION IN AN IN-VIVO ANIMAL EXPERIMENT

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Abstract: *Quantitative experimental evidence for the influence of skull defects on the MEG is rare. This study aims to experimentally investigate the influence of conducting skull defects on the MEG and EEG signal and source reconstruction using a controlled current source under a skull defect and a detailed finite element head model. Our results demonstrate that both EEG and MEG were influenced by a conductive skull defect with a maximal relative magnitude deviation of above 300% for EEG and above 20% for MEG. Failure to model skull defects in MEG source reconstruction can lead to localisation and orientation errors. A realistic finite element head model is able to represent a skull defect and to compensate its influence on the MEG source reconstruction. We conclude that skull defects need to be accounted for in realistic volume conductor models.*

Keywords: *Finite element method, biomagnetism, volume conduction, breach rhythm, rabbit.*

Introduction

While the influence of skull defects on the electroencephalogram (EEG) has been reported, the magnetoencephalogram (MEG) is thought to have a negligible sensitivity to skull defects. However, quantitative experimental evidence under realistic conditions is rare. Our objective is to experimentally investigate the influence of conducting skull defects on the MEG and EEG signal and source reconstruction using a controlled current source under a skull defect and a detailed finite element head model.

Methods

Ethics approval was obtained (Freistaat Thüringen, Germany, 02 034/08) for the study. We measured a 64-channel EEG simultaneously to a 16-channel MEG produced by a miniaturized artificial coaxial dipole implanted in a rabbit brain tangentially to the inner skull surface in vivo. Following a recording with intact skull, a skull defect was introduced above the dipole and filled with agar (1.0 S/m at 30°C). A CT (0.4 mm^3) provided the defect geometry and the dipole position. The dipole was shifted in 0.35 mm steps from a position next to the skull defect to a position under the defect and further to the opposite side and a recording was taken at each step under otherwise identical conditions.

To quantify the topographical and magnitude deviation caused by the first and the combination of the first with the second skull defect, we determined the relative difference measure RDM* and relative magnitude deviation MAG_{rel} [1]. The CT was co-registered with and resampled into the same space as a pre-experimental T2 MRI of 0.4 mm^3 of the rabbit's head. The body, ocular humour and lens, compact and cancellous bone, skull defects and brain compartment were segmented based on the geometrically most accurate CT. The white matter, CSF and intracranial blood vessels were segmented from the T2 MRI. A cubic mesh (Figure 1) was derived from the segmented voxel dataset using the Vgrid software [2]. A node shift was applied to smooth the surfaces between adjacent compartments. Tissue conductivities, where possible specific to rabbits, were derived from the literature (Table 1) [3].

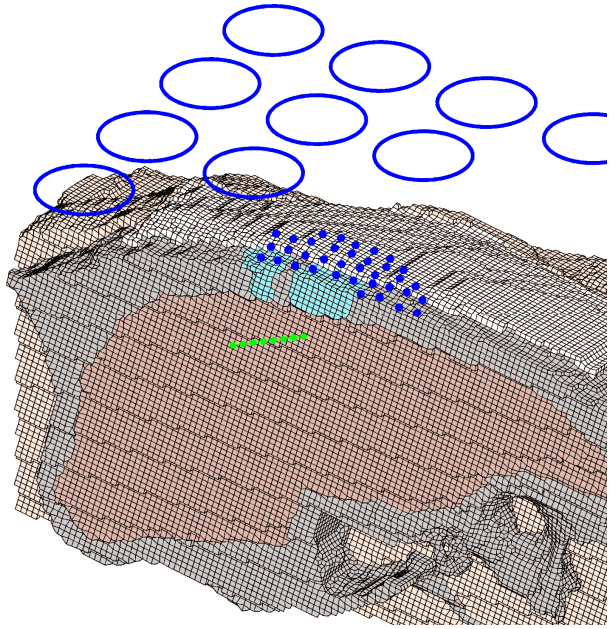

Figure 1: Finite element rabbit head model sliced open in multiple sagittal planes showing the skin (beige), skull (grey), brain (brown) and skull defect (turquoise) compartments; the saline layer (white) beneath the EEG (blue dots); the MEG (blue circles) and the sequence of positions of the controlled current source (green dots).

Table 1: Tissue types and equivalent conductivities.

Tissue	Conductivity S/m
Scalp/body tissue	0.33
Compact bone	0.004
Cancellous bone	0.046
Grey matter	0.23
White matter (isotropic equivalent)	0.7
Cerebrospinal fluid	1.79
Intracranial blood vessels	0.78
Ocular humour	1.7
Ocular lens	0.35
Agar in defect	1.0
Liquid layer under EEG	0.6

The EEG and MEG were forward simulated using a blurred dipole approach implemented in the SimBio software toolbox [2]. The EEG reference was attached equivalently to the experiment at the anterior snout.
Source reconstruction from the MEG were performed using an unconstrained moving dipole fit with an initial guess at the source position derived from the CT and an initial simplex size of 1cm. The component of the reconstructed source normal to the MEG plane was excluded, because the monodirectional geometry of the MEG array did not allow sufficient detection of it and because physical source orientation was almost parallel to the MEG plane. The EEG coverage was insufficient for source reconstruction without further a priori constraints.

Results

Our results demonstrate that both EEG and MEG were significantly and reproducibly influenced by the introduction of a conductive skull defect with a maximal relative magnitude deviation of above 300% for EEG and above 20% for MEG. The finite element simulation qualitatively and quantitatively matches these findings (not shown).
The sources reconstructed from the MEG (Figure 2) are arranged in a sequence in space. The explained variance was larger than 99% in every case. The intact skull recording sources are less than 1 mm away from the source locations derived from the post-experimental CT. The sources from the skull defect MEGs reconstructed with an intact skull model are displaced away from the defect. Their orientation is altered from the implanted source direction to point more radial to the skull defect boundary. When the sources are instead reconstructed with a head model incorporating the skull defects, the displacement in the X-Y plane is reduced to a large degree and the orientation parallel to the shift line is restored.

Discussion

The results from a realistic skull defect experiment show that failure to model skull defects in MEG source reconstruction can lead to localisation and orientation errors. A realistic finite element head model is able to represent a skull defect and to compensate its influence on the MEG. We conclude that skull defects need to be accounted for in realistic volume conductor models used in the reconstruction of brain activity sources from MEG and EEG, particularly in infants with open fontanels and patients with post-surgical skull conditions.

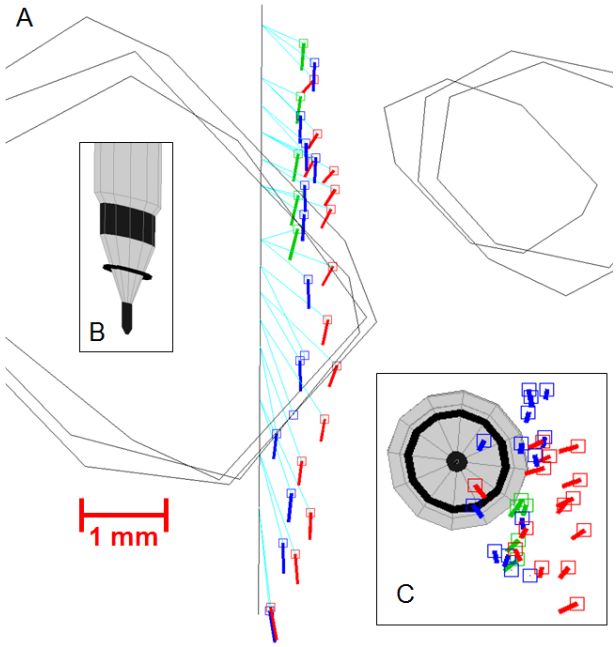

Figure 2: Planar (A) and axial view (C) of the successively recorded dipolar sources along the shift line (black) reconstructed from MEG above intact skull (green), from MEG above two skull defects using an intact skull head model (red) and from MEG above two skull defects using a skull defect head model (blue); Respective source position derived from the post-experimental CT is indicated with light blue lines; Dipole implant shown approx. to scale (B).

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