

## ***Electromagnetic Simulation Used to Evaluate Safety of Combining EEG and MRI***

Electromagnetic simulation software is being used to investigate the safety of an important research technique that integrates electroencephalography (EEG) with magnetic resonance imaging (MRI). The integration of these two analysis methods has the potential to improve investigations of brain activity because EEG offers high temporal resolution while MRI offers high spatial resolution. But concerns have arisen about temperature increases in sensitive brain tissues that could be caused by the current induced in the EEG electrodes by the radio frequency (RF) power generated by MRI. Leonardo Angelone and Dr. Giorgio Bonmassar, researchers at the Massachusetts General Hospital/Massachusetts Institute of Technology/Harvard Medical School Athinoula A. Martinos Center for Biomedical Imaging, Charlestown, Massachusetts, simulated the RF power dissipated in the human head in an integrated MRI-EEG software simulation. Their results (Angelone et al. 2004) showed that in particular cases, such as high magnetic MRI fields and use of metallic EEG leads, the specific absorption rate (SAR), which measures tissue exposure to RF, is four to seven times higher than in MRI alone, indicating that power levels need to be reduced in integrated experiments.

One of the most important challenges in brain imaging is to model the sources of brain activity during different visual, auditory or motor tasks. Brain mapping with MRI has the highest spatial resolution of current non-invasive imaging techniques. The spatial resolution of MRI is typically millimeters in the case of human subjects. However, because MRI measures primarily a hemodynamic response with a time constant on the order of seconds, the precise mechanics of information exchange within the brain, which occur on a millisecond scale, remain hidden. EEG, on the other hand, can provide temporal accuracy in the required millisecond range but the spatial accuracy is only on the order of centimeters. Researchers have been working to integrate MRI and EEG in order to combine the spatial resolution available with MRI and the temporal resolution offered by EEG.

**Safety concerns arise**

However, this emerging research technology raises rare but real safety issues. The use of electrodes in an MRI environment is in many respects similar to the presence of metallic implants in an MRI environment, which has already been addressed in several studies. These studies have shown that when heating of tissues are present, these depend in the area of the implant is a function of the dimensions, orientation, shape, and location of the implant in the patient. Furthermore, in the case of metallic wire, which is particularly relevant to the integrated EEG-MRI case, the location of heating in the tissue is usually concentrated in a small volumetric area near the tip of the wire. These results highlight the importance of specific studies involving EEG electrodes in the presence of an RF field.

Angelone and Bonmassar used electromagnetic simulation to measure the RF energy absorbed by the human head in an integrated EEG-MRI experiment. They selected the XFDTD Version 6.1 software from Remcom Inc., State College, Pennsylvania, which incorporates a full-wave, three-dimensional solver based on the finite difference time domain (FDTD) method. According to the Federal Communications Commission of the United States as stated in OET Bulletin 65, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields", Supplement C: "Currently, the finite-difference time-domain (FDTD) algorithm is the most widely accepted computational method for SAR modeling." Furthermore, in FCC Part 95 Section 603(f) it is stated: "Applications for equipment authorization of devices operating under this section must contain a finite difference time domain (FDTD) computational modeling report showing compliance with these provisions for fundamental emissions." Remcom provides FDTD heterogeneous head and body models, together with software that allows repositions of the limbs. In addition they provide the Specific Anthropomorphic Mannequin (SAM) head as a CAD file that may be oriented and meshed at any desired resolution within XFDTD to aid customers in complying with FCC limits on SAR.

### **Modeling an MRI-EEG experiment**

Due to the particular spatial resolution needed for their research, Angelone and Bonmassar developed their own high-resolution head models by meshing the anatomical MRI data of two adult male subjects. The brain was segmented into cerebrospinal fluid, gray matter, and white matter, using a hybrid method combining watershed algorithms and deformable surface techniques.

Using the XFDTD Geometric Modeler they constructed a FDTD model of a bird cage coil composed of sixteen 300 mm perfect electrical conductor rods, closed by two 260 mm diameter, 1 mm thick loops at each end, and placed symmetrically around the head. Using the standard features available in XFDTD, a circular excitation was simulated, driving the current generators placed on the centers of the rods with 1 A peak-to-peak amplitude and a 22.58 degree phase-shift between any two adjacent generators. The surface coil used was a circular perfect electrical conductor, oriented in the XZ plane with a diameter of 140 mm and thickness of 1 mm. The current source, a sinusoidal generator of 1 A peak-to-peak amplitude with internal resistance of 50 ohms, was placed on the lowest point of the ring.

SAR is the variable typically used to quantify the effects on tissue exposure to RF signals. SAR is defined as the time derivative of the incremental energy absorbed by an incremental mass contained in a volume of given density (NCRP 1981). Again using standard postprocessing features in the Bio-pro module, XFDTD was used to compute the electric and magnetic fields and the SAR. Simulations were performed with surface and birdcage MRI coils; 16, 31, 62, and 124 electrodes; and at 128 and 300 MHz. An Athlon PC was used for the calculations.

### **Simulation shows higher SAR values**

The results confirmed an average of up to seven times the original value in averaged SAR on the skin as well as an increase in the tissues adjacent to the electrodes. The difference in SAR between the electrodes and no-electrodes conditions was greater with the bird cage coil than with the surface coil. The peak 1 g averaged SAR values were highest at 124 electrodes, increasing to as much as two orders of magnitude at 300 MHz compared to the original value. At 300 MHz, there was a fourfold increase of SAR averaged over the bone marrow, and a sevenfold increase in the skin. The study shows that the presence of nonmagnetic high conductive metallic EEG electrodes can increase the peak SAR on the subject by as much as 172 times.

The simulation also showed that with the electrodes and leads, because of the RF induced currents along the leads, the electric field increases near the electrodes. Thus, the electrodes increase the electric field on the skin and on the surrounding tissues. This generates an increase of peak SAR values for

both surface and bird cage coils, relative to that produced by the RF of the coil only.

A growing number of laboratories are performing EEG recordings during MRI. The research described here indicates that the pulsed RF fields that are used to elicit MRI signals from tissue may pose a safety hazard by inducing currents in the EEG electrodes/leads. Safety issues, a relatively minor problem at 1.5 Tesla (Mirsattari et al., 2004), may be present at higher fields when using purely metallic EEG electrodes/leads. The electromagnetic simulations performed by Angelone and Bonmassar quantified the resulting SAR for different RF coil types, numbers of electrodes and frequencies. Their results, computed by using the FDTD technique available in the Remcom software, confirmed an increase of up to seven times the averaged SAR on the skin and as much as 172 times for peak 1 g averaged SAR compared to MRI performed without metallic EEG electrodes. The FDA guidelines (FDA 2003) for use in MRI environments recommend SAR levels lower than 3 W/kg averaged over the head for 10 minutes and 8 W/kg in any gram of tissue in the head for 5 min. The conclusions to draw from this study are that in order to comply with the FDA recommendation, the maximum input power used for an MRI sequence needs to be reduced when using metallic EEG electrodes/leads respect to the case without EEG electrodes/leads.

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