On the use of resistances on the EEG leads: SAR and temperature study

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INTRODUCTION. Simultaneous EEG-fMRI recordings represent an invaluable investigation tool in research and clinical settings [1-3]. The interactions between EEG electrodes/leads and the RF coil affect both image quality and safety. Currently, most of the recordings are safely performed at low $\mathbf{B_0}$ field MRIs (up to 1.5T) using low power sequences [2]. The tendency of the research is using an increasing number of EEG electrodes and higher MRI fields (up to 7T) in order to increase the data quality. Recent simulation studies showed increase of SAR due to the distortions caused by the leads on the $\mathbf{B_1}$ field [4]. One possible solution is to increase the resistance of the leads and there are two possible ways of doing so: resistance (1) distributed on the lead or (2) concentrated near the electrode. Using SAR simulations, temperature estimations and measurements we show that the concentrated resistance solution does not eliminate the distortions of the $\mathbf{B_1}$ field and the rare but real SAR issues.

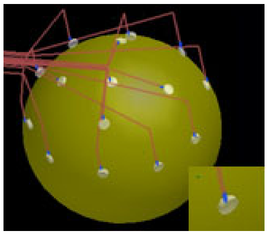

Figure 1. *Graphical view of the geometrical model used in the FDTD simulations.*

METHODS. *Conductive Phantom***.** A ***conductive*** spherical solid phantom (1.8l H_2O, 42gr. Agarose composite hydrogel, 3.6gr) with a diameter of approximately 14cm was built and used for all temperature measurements**.** A set of non-magnetic EEG electrodes/leads was uniformly positioned on top of the phantom using a cap. The electrodes were directly touching the phantom surface, ensuring electrical connection between leads and the phantom itself. The following phantom configurations were studied: a) alone, b) with 15 electrodes/leads and c) with 15electrodes/leads + 10KΩ "RF" resistances near each electrode (**Fig. 1**). The conductivity of the copper leads was σ=0.1Ω/m**.** *FDTD Simulations*. FDTD Simulations (XFDTD, Remcom Co., USA) were performed with birdcage coil [4] at 128MHz and 300MHz on the three cases (a-b-c) described above**.** *RF measurements***.** RF field maps (3T Siemens Trio, 2D spin echo sequence) were measured for the three cases (a–b-c) with a standard MRI phantom**.** *Temperature Measurements***.** A 3100 Fluoroptic Thermometer with two probes (Luxtron Co., USA) was used for the measurements. One probe was placed about 7cm inside the phantom, the second one below one electrode (about 4mm inside the surface). Measurements were conducted using high power sequences with 3T Siemens Trio (20 min T2-TSE sequences, 0.1W/Kg Whole body SAR reported) and with custom made 7T whole body system retrofitted with a Siemens console (15 min T2-TSE sequences, 0.4W/Kg Whole body SAR).

RESULTS AND DISCUSSION. *Simulations.* The peak SAR value was inside the phantom model in case (a) whereas near the electrode in cases (b) and (c) (**Fig. 2**). There was no difference on averaged SAR values between (b) and (c). The SAR distribution was in general more homogeneous at 128MHz than at 300MHz as expected**.** *RF measurements.* The RF field distribution was different between case a) and b), but no difference was noticed between b) and c)**.** *Temperature measurements and heat equation solution*. A higher increase of temperature (+0.5°C) was measured with the electrodes respect to the phantom alone (**Fig. 3**)**.** As in the simulations, opposite results were obtained inside the phantom**.** The different SAR computed by the simulation was used as heat source in the evaluation of conduction-only heat transfer equation:

$$\rho C_\rho \frac{\partial T}{\partial t} - \nabla \bullet (k \nabla T) = SAR_\rho$$

[5]. The phantom's heat coefficients: heat capacity = 4,500 J/Kg/C and thermal conductivity = 0.5 W/m/C were found by fitting the heat equation solution to the measurements (**Fig. 3**). Local SAR values considered were 8 W/Kg (case a) and 16 W/Kg (cases b) as computed by the simulations.

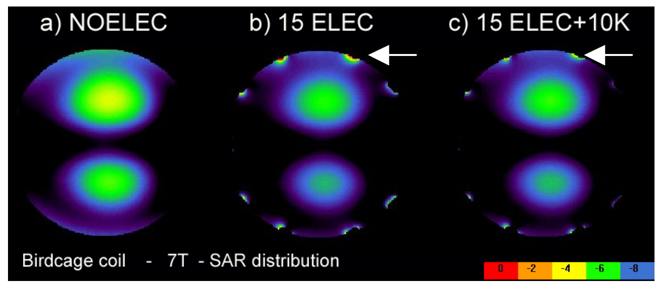

Figure 2. *SAR simulations at 7T with phantom: (a) alone, (b) with 15 electrodes,(c) with 15elec+10KΩ resistances. The peak SAR was inside in (a), whereas hot spots were present on the surface in (b) and (c) (white arrows). Average and peak SAR values were the same in (b) and (c)*

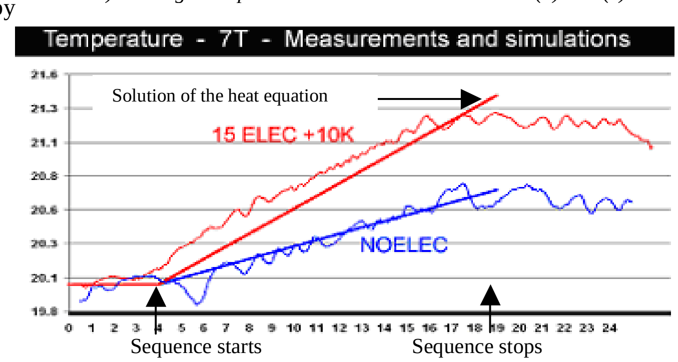

Figure 3. *Temperature measurements and estimation on the surface of the phantom at 7T. Red: 15elec+10K, blue no electrodes. The measured temperature trend matched the numerical solution of a simplified heat equation (straight lines).*

CONCLUSIONS. Using SAR simulations, temperature estimation (i.e., solving the heat equation) and measurements we showed that the use of RF resistors on the EEG leads does not eliminate the distortions of the B1 field and the rare but real SAR issues. We observed that the temperature measurements with EEG electrodes/leads were affected by the relative position of the sensors respect to the electrodes, the geometry of the leads and, most importantly, by the contact impedance between EEG electrodes/leads and tissue measured**.**

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