A Novel Method for Experimental Assessment of Antenna Safety Using MR Thermometry

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INTRODUCTION: Electromagnetic field simulations are often used to characterize the interaction between an antenna and a load for safety assessment of the RF antennas. However, modeling of complex antenna-load structures to match the physical setups using electromagnetic (EM) field simulations are not straight-forward[1]. In addition to using EM field simulations to evaluate antennas, E-field probes are often used experimentally to assess the safety of RF antennas[2] by mechanically moving the probes in a grid-like fashion in 3D space inside a phantom filled with a liquid mimicking the electrical properties of human tissues. This process is often time consuming because of the need for high experimental resolution and, thus, cost inefficient. Conversely, MR thermometry[3] has been successful for monitoring small temperature changes. In this work, we propose an alternative method for safety assessment of RF antennas that is based on temperature measurements on the physical antenna-load setup along with heat capacity measurements. Using a simple dipole antenna-phantom setup, it is shown that MR thermometry could be used experimentally to rapidly assess safety of complex antenna-load structure, while measuring the temperature change which is directly related to EM safety.

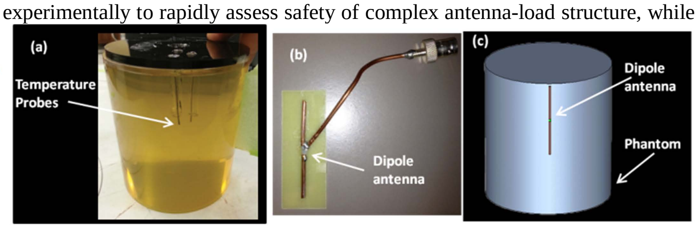

Figure 1 (**a**) Phantom with probes, (**b**) Dipole antenna and (**c**) FDTD simulation setup

METHODS: A cylindrical acrylic former [Fig. 1a] with a diameter of 10.2 cm and a height of 11cm was filled with gelatin by combining 600 g of sucrose (>99% Sigma-Adrich, St. Louis, MO), 450 ml of distilled water (Sigma, St. Louis, MO) and 54g of gelatin (Kraft, Northfield, IL). A dielectric probe was used to measure the conductivity and relative permittivity (Agilent 85070E, Santa Clara, CA), which were σ=1.5 S/m and ε_r=35, respectively, emulating the electrical properties of the human brain at 1.96GHz – emulating a dipole antenna operating at GSM frequency. Additional properties of the phantom were ρ=1010 kg/m^3 (material density), c=3543 J/kg/°C (heat capacity), D=0.129 mm^2/sec (diffusion length), and k=0.457 W/m/°C (thermal conductivity), which were measured using thermal properties analyzer (KD2 Pro, Pullman, WA, USA).

A 5.5 cm long dipole antenna (Fig. 1c) was built using a copper coaxial cable. Network analyzer (Agilent E5070B) was used to feed two stage power amplifiers (drive stage: AH212, final stage: AH420, Triquint Semiconductor, Oregon, USA) which are connected to the dipole antenna. A directional coupler (Agilent 778D) was used to measure the net power delivered to the dipole antenna, which was used to scale power in FDTD simulations. Net power delivered to the dipole antenna was 0.61W.

RF heating produced by dipole antenna was measured using a 3T MR scanner and a head and neck coil (Siemens Medical Solutions). Multislice GRE measurements of the phantom before and after heating period of 5 mins were acquired with the following parameters: TR/TE=422/20 ms, voxel size = 2x2x4 mm^3, flip angle = 10 degrees, number of averages = 4, number of slices =19 and total acquisition time = 107 secs. The proton resonance frequency shift method[2] was used to convert 3D GRE phase measurements into a temperature difference map of the heating caused by dipole antenna, where α, the proton frequency shift coefficient, was set to 0.009 PPM/°C, as measured experimentally for the phantom. Additionally, three fluoroptic probes (Luxtron M3300) (Fig 1a) were used to measure temperature during RF heating. FDTD (CST Microwave Studio 2012) simulations were performed on the dipole antenna - phantom setup (Fig 1b) to obtain SAR distribution of the dipole antenna. SAR distribution and thermal properties of the phantom were used to model the temperature distribution within the phantom solving the following Heat equation[4] $\frac{dT}{dt} = \nabla.(k\nabla T) + SAR\rho$. Similarly, the modulus of the E-field was approximated from experimental data as $\|E\| \cong \sqrt{\frac{2\rho c\,\Delta T}{\sigma \Delta t}}$, where Δt is the heating duration and ΔT is the temperature change measured using MR thermometry. Diffusion length during experiments was calculated to be 7.2 mm (3.5 voxels in plane, 1.8 voxels in slice direction).

RESULTS: Fig. 2 shows temperature measurements inside the phantom acquired using the fluoroptic probes. The maximum heating captured from the probe measurements was 0.86 °C (Probe A) as a result of 5 mins RF heating period (minutes 5 to 10 in Fig. 2a). MR thermometry results show a good agreement with the optical temperature measurements, as indicated by the locations of the probes (Fig. 2b) and temperature values in Fig. 2c. Fig. 2d shows the temperature simulation results using SAR values calculated from FDTD simulation and measured thermal properties of the phantom. Results from the simulated dipole antenna match the experimental results very well both in pattern and magnitude (Fig. 2c and 2d). Similar behavior was observed on the E-field norm and SAR measurements as shown in Fig 2e-h.

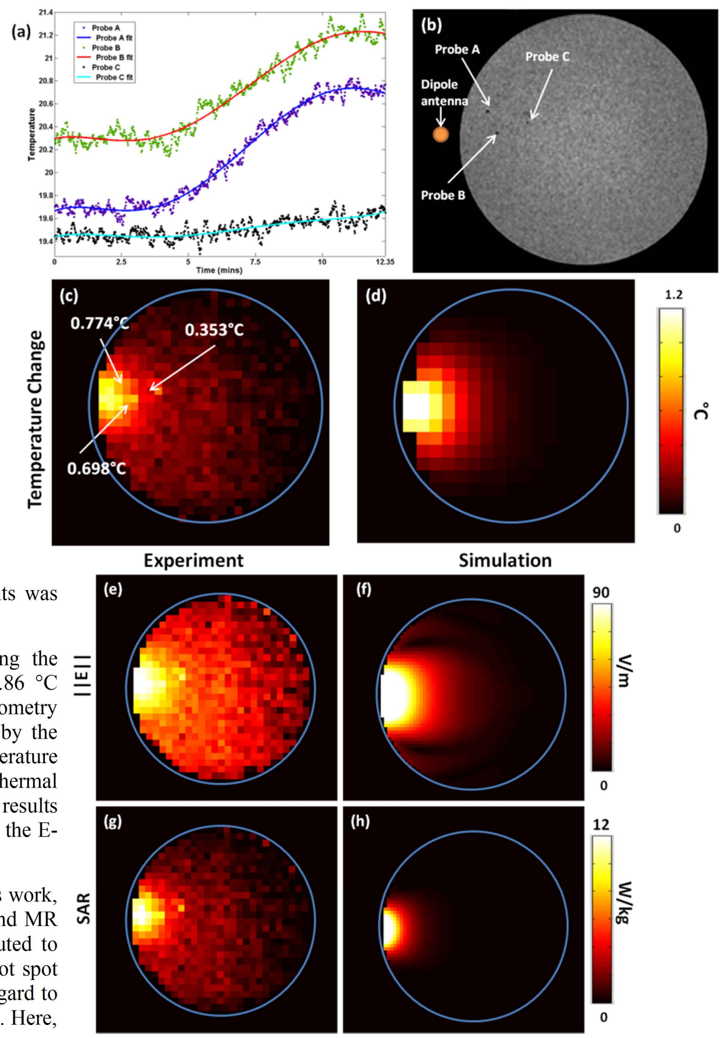

Figure 2 Fluoroptic temperature measurements (**a**) with their locations within the phantom (**b**). MR Thermometry measurement of the phantom is shown in (**c**) with simulated temperature map is shown in (**d**). Experimental ||E|| and SAR maps are shown in (**e**) and (**g**), respectively. Simulation results for ||E|| and SAR are shown in (**f**) and (**h**), respectively. Blue circle represents the phantom boundary

DISCUSSION: Simulating a complex antenna-phantom setup can be a difficult task. In this work, we demonstrate a method to estimate SAR and ||E|| based on heat capacity, conductivity and MR thermometry measurements. In the current experimental setup, the heat diffusion contributed to some blurring of the SAR and |E| maps, however, the location and the magnitude of the hot spot was still captured accurately. The experimental method is particularly advantageous with regard to speed and its ability to assess the safety of complex antenna structures at various frequencies. Here, we demonstrate good agreement between MR thermometry and probe measurements in a phantom. Having produced robust results in a phantom with a maximum temperature increase less than 1°C, we intend to evaluate possibility to perform similar experiments *in vivo*.

REFERENCES: [1] Chavannes N, et al. (2003) IEEE Antennas and Propagation (45): 52-66. [2] Schmid T, et al. (1996) IEEE Microwave Theory and Techniques (44):103-15. [3] Ishihara et al. (1995) MRM 34: 814-823. [4] Collins, et al. (2004) JMRI (5):650-6.