Investigation of Different RF Coil Safety Assessment Techniques: E-field Measurements, EM Field Simulations and MR Thermometry

Cem Murat Deniz[1,2], Leeor Alon[1,2], Gene Y Cho[1,2], Ryan Brown[1], Christopher M Collins[1,2], and Daniel K. Sodickson[1,2]
[1]*The Bernard and Irene Schwartz Center for Biomedical Imaging, Department of Radiology, New York University School of Medicine, New York, NY, United States,*
[2]*The Sackler Institute of Graduate Biomedical Sciences, New York University School of Medicine, New York, NY, United States*

PURPOSE: Safety assessment of RF coils for MRI often relies upon electromagnetic (EM) field simulations due to the lack of an accurate means to experimentally measure the electric fields inside the human body. Experimental B_1^+ maps[1] are often used to estimate the accuracy of EM field simulations. Additional validation for the EM field simulations are increasingly performed using electric (E) field probes[2] and/or thermal measurements with temperature probes[3],though these techniques may be limited to homogenous phantoms and to comparatively crude spatial resolution, respectively Recently, MR thermometry has been used for assessing the safety of RF coils[4,5,6]. In this work, we investigate these three different RF safety assessment techniques using a dipole antenna adjacent a standardized head phantom.

METHODS: A half wavelength dipole antenna operating at 1.96GHz (Fig. 1A) was chosen as a heat source because of its prevalent application in wireless devices and its opacity in MR experiments. In E-field and MR thermometry experiments, power input to the dipole antenna was measured using a directional coupler (778D, Agilent Technologies) and power meter (NRP-Z11, Rhode & Schwarz). The power input in MR thermometry experiments was then used to scale the input power of EM field simulations and E-field measurements.

E-field measurements of the dipole antenna using the standardized Specific Anthropomorphic Mannequin (SAM) head phantom filled with tissue-simulating liquid were performed in a DASY52 system (Fig. 1D; SPEAG) with E-field probe (EX3DV3, SPEAG). Measurement locations covered a volume grid of 11x13x7 locations with $(10mm)^3$ resolution within the proximity of the dipole antenna. Liquid properties were: σ = 1.385 S/m, ε_r = 39.12 and ρ = 1000 kg/m^3.

EM field simulation of the dipole antenna and SAM head phantom setup was performed using an FIT technique in Microwave Studio (CST v2013, MA, USA). E-field distribution within the phantom was exported with 10 mm^3 resolution.

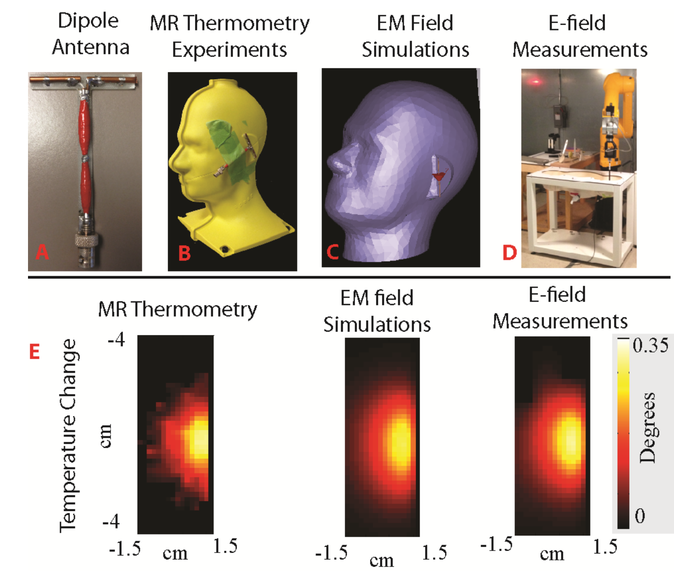

Figure. A: 1,96 GHz Dipole antenna. **B:** SAM head gel phantom and dipole antenna setup used in MR experiments. **C:** EM field simulation setup. **D:** DASY52 system which was used in E-field measurements. **E:** Temperature change maps from different RF safety assessment methods, obtained in axial plane close to the center of the dipole antenna

MR thermometry experiments with the dipole antenna and a gel filled SAM head phantom (SAM-V4.5BS, SPEAG) were performed at 3T using a 32 channel head coil array (Tim Trio, Siemens). 3D spoiled GRE images of the phantom before and after dipole antenna heating for 5 minutes were acquired with following parameters: TR= 23 ms, TE = 20 ms, voxel dimension = 4x4x5mm^3, flip angle 15° and acquisition time = 29 s. Temperature difference maps were produced using the proton resonance frequency (PRF) shift method. Phase drift unrelated to temperature was removed by estimation via 6th order polynomial fitting derived from multiple external oil phantoms and internal regions far from the heat source[7]. The PRF shift coefficient (0.009 PPM/°C) was determined with fluoroptic temperature probes (M3300, Luxtron).

The SAR distribution of the dipole antenna calculated from E-field measurements (interpolated to 2mm isotropic resolution) and thermodynamic simulations were used to calculate the temperature distribution after heating with the antenna for 5 minutes using a finite difference based temperature simulator[8]. For temperature simulations, phantom thermal properties measured with a thermal properties analyzer (KD2 Pro, Pullman, WA, USA) were used: C=2960 (J/kg°C) and k=0.347 (W/m°C). The maximum 10 g average SAR was calculated directly from E-field measurements and EM field simulations, and in MR thermometry experiments by heat equation inversion[9] using temperature difference maps and thermal properties of the phantom.

RESULTS: Figure 1E shows the temperature distribution of the dipole antenna using three different techniques. The maximum temperature change and maximum 10g average SAR within the phantom was 0.31°C and 3.4 W/kg for the probe measurements, 0.29°C and 3.04 W/kg for the simulations, and 0.35°C and 2.92 W/kg for MR thermometry.

DISCUSSION: We performed experiments and simulations to investigate three different RF safety assessment strategies. All three methods produce similar maximum 10g SAR and peak temperature increase. Obtaining 3D spatial information using E-field measurements may require multiple probes and/or movement of the probe which can be inefficient in time, may require costly equipment, and may be limited primarily to homogeneous phantoms. These results suggest that MR thermometry is a valuable tool for transmit array safety assessment which is being readily available in any MR scanner.

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