Multi-channel Array Safety Simulations Validated with Field and Temperature Measurements

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PURPOSE: Evaluation and prediction of local SAR during RF excitation have commonly relied upon electromagnetic (EM) field simulations due to a lack of accurate means of measuring and predicting electric fields inside the human body. In order to precisely quantify the localized RF energy deposition inside the body, accurate numerical representation of the RF array and the human body is necessary. Experimental B_1^+ maps have been used to estimate the accuracy of RF array representation in EM field simulations[1]. Additional validation for the EM field simulations have been performed using electric field probes[2] and/or thermal measurements with temperature probes[3]. However, obtaining 3D spatial information requires movement of the probes/multiple probes in which can be time- and cost- inefficient. In the past, MR thermometry has used to assess the RF safety of a surface and quadrature coils[4] and a simple dipole antenna[5]. In this work, we investigate the use of MR thermometry for verification of EM field simulation of a complex multi-channel array structure in addition to amplitude and phase MR B_1^+ field measurements.

METHODS: EM field simulation of an 8-channel array and torso phantom setup (shown in Fig. 1A) within the MR RF shield was performed in CST Microwave Studio. Each coil was tuned at 297.2 MHz and matched using S-parameter analysis by aligning with S-parameter measurements. Diagonal entries of the S-parameter matrix were matched within 8% of the measured values and next-neighbor elements were within 25%. 17.8 million mesh cells with edge lengths ranging from 0.15 mm to 25.6 mm were used in the EM field calculations. Electric and magnetic field distributions from each coil were recorded for comparison to the MR field and temperature measurements. The SAR distribution of a predefined RF shim and thermal properties of the phantom were used to model temperature distribution from heating with the array for 10 minutes 20 seconds using a finite difference based temperature simulator[6].

In experiments, flip angle maps for each channel were acquired using both AFI and eight low flip angle multi-slice interleaved GRE acquisitions with TR=150 ms, TE=2ms, nonselective RF length/amplitude=500us/100V, voxel dimensions=3.5mm isotropic, flip angle 20°, and acquisition time=20min. An acrylic torso phantom (50cm length, 20cm height and 30cm width) was filled with gelatin-based semi-solid (combination ratio by weight: 0.07% benzoic acid, 36.7% water, 55% sugar -Domino Sugar, NY, USA, 3.7% salt, 4.6% gelatin - Knox Kraft, IL, USA). The electrical conductivity and relative permittivity of the torso phantom were 0.58 S/m and 41, respectively, as measured by a dielectric probe (Agilent 85070E, CA, USA). The heat capacity, thermal conductivity, and density were 3023 (J/kg°C), 0.404 (W/m°C) and 1347 (kg/m^3), respectively, as measured by a thermal property probe (KD2 Pro, WA, USA). RF heating produced by the array with a predefined RF shim was measured in a 7T MR scanner using multi slice GRE measurements before and after heating and the proton resonance frequency shift method[7]. Parameters for the GRE measurements were TR = 20ms, TE = 5ms, voxel dimensions = 3.5x3.5x10mm^3, flip angle 20°, and acquisition time=8s, number of slices=3.

RESULTS: Figure 1B shows the amplitude and relative phase of simulated and experimental B_1^+ maps on a central axial slice. The amplitude B_1^+ map correlation between experiments and simulations was > 0.91. RF shimmed B_1^+ maps resulted in 9% overestimation of B_1^+ at the location of its maximum value. Experimental and simulated temperature difference maps of one particular RF shim setting are shown in Fig. 1C. Simulations resulted in higher maximum temperature change than did experiments. The location of the maximum RF heating was predicted accurately in simulations, indicating the validity of electric field phase relations of individual channels.

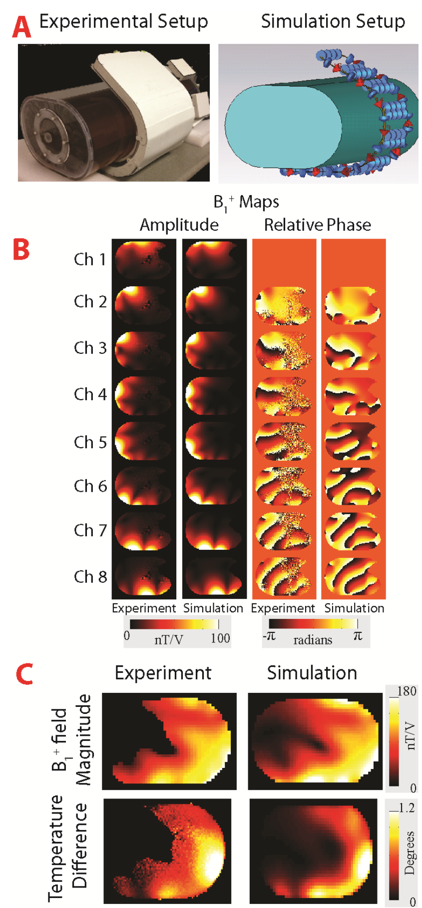

Figure 1. **A:** Experimental and EM field simulation setup. **B:** Individual channel amplitude and relative phase maps of B_1^+ from experiments and simulations **C:** B_1^+ maps and temperature difference maps for a specific RF shim setting.

DISCUSSION: We performed S-parameter, B_1^+ field and temperature measurements in order to estimate the validity of the EM field simulation of a multi-channel array with complex geometry. Temperature measurements were used as an additional validation for MR field measurements. Simulations resulted in overestimation of the B_1^+ obtained in experiments, which could be minimized by characterizing the RF chain losses more thoroughly, even though the overestimation provides an additional safety factor for simulations. While the location of maximum temperature change was predicted accurately in simulations, simulations resulted in higher maximum temperature changes than measurements. This may be attributed in part to simulation field overestimations, thermal property measurement uncertainties, and high sugar content of the phantom. Validation of hot spot locations with MR thermometry measurements increases confidence in the coil representation in EM field simulations.

REFERENCES: [1] Van den Berg CAT et al. (2006) Physics in Medicine and Biology 51(19): 4735-46. [2] Bitz AK et al. (2011) ISMRM p490. [3] Graesslin I et al. (2012) MRM 68(5):1664-74. [4] Cline H et al. (2004) MRM (51):1129-37 [5] Deniz CM et al. (2013) ISMRM p4424. [6] Collins C et al. (2004) JMRI (5):650-6.[7] Ishihara et al. (1995) MRM 34: 814-823