Difficulties Associated with Aligning Simulated and Constructed Coils

Leeor Alon[1,2], Cem Murat Deniz[1,2], Ryan Brown[1], Daniel Sodickson[1,2], and Yudong Zhu[1,2]

[1]*Department of Radiology, Bernard and Irene Schwartz Center for Biomedical Imaging, New York University, New York, NY, United States,* [2]*Sackler Institute of Graduate Biomedical Sciences, New York University, New York, NY, United States*

Introduction: Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed by the body when exposed to an RF field and is a measure of safety with regard to RF heating as defined in FDA and IEC guidelines [1,2]. Extensive efforts for evaluation and prediction of local SAR have relied upon results from electromagnetic field (EM) simulations software calculating the EM fields generated in "average" subjects. Finite difference time domain (FDTD) method or finite element method (FEM) have often been used as a development platform for evaluating performance of many EM wave applications and specifically for MR coil safety and performance. Typically, coil structures are modeled in simulation software and field patterns associated with the RF coil-subject setup are computed. These simulations are routinely conducted for both single and multiple transmit coil arrays, however the geometry of the coil needs to be accurately modeled in order to appropriately simulate the E, B and SAR distributions generated by the coil. As the actual current density path in the coil is unknown, this abstract shows that once a perturbation is made to the conductive path of the coil structure, maximum E and SAR changes can be significant. This change in field distribution is also seen to increase with field strength, suggesting possible drawback when relying on simulation software with hypothetical setups to account for safety of coil structures at high field strengths.

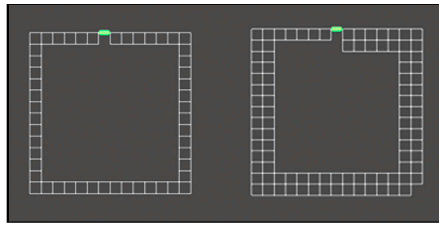

Figure 1. A: Original (left) and B: altered (right) surface coils used in full wave EM field simulations.

Methods and Results: Commercially available FDTD software (xFDTD. Remcom. PA, USA) was used to test the extent of change in E, B1+, Bz and SAR distributions when the surface coil structure geometry is altered. A surface coil measuring 7 x 7 cm^2 was placed 1cm above the abdominal area of a Hugo human body mesh model. A 1-ampere current source was defined at the coil and the convergence criterion for was set to -60dB. The resolution was set to 5 mm^3 isotropic and the grid size was 155x110x416. In order to evaluate the effect of coil geometry on simulated field maps two simulations were conducted. Hugo human mesh model was placed under a simple surface coil (Figure 1A) for Simulation 1 and a surface coil which was altered by adding perfect conducting wires in a nonsymmetrical fashion (Figure 1B) for Simulation 2. This new coil geometry generated for Simulation 2 forced the current density generated by the original coil to change. Since, the true current density distribution on the coil is not known in detail and mismatch between the coil simulated and the physical coil used in the scanner (for example, wiring of the coil or positioning of the capacitors on a coil might may be different). Simulations were run with an RF frequencies set to 64, 128 and 297 Mhz, respectively, simulating the carrier frequencies at 1.5, 3 and 7 T. After the simulation converged, the resulting B_1^+, E, SAR and B_z distributions were exported into Matlab (version 7.11, MathWorks, Inc., Natick, MA, USA) for post processing. Figure 2 illustrates an axial slice positioned under the coil of the B_1^+, E, SAR and B_z distributions where the percentage difference and the norm of the complex difference between the original and altered simulations are presented. Although the percent difference of the B_z component is very high, the norm of the difference is small compared to B_1^+ magnitude. Figure 3 plots the mean % error (red lines) and standard deviation of the error (black error bars) between the original and altered simulations over the slice of interest.

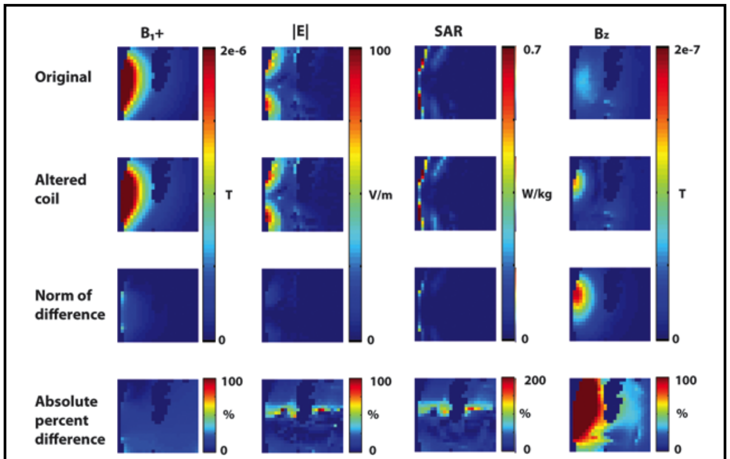

Figure 2. The norm of the complex difference and the absolute percent difference plots for 3T. Changes in the coil structure altered SAR significantly while leaving $|B_1^+|$ fields unperturbed.

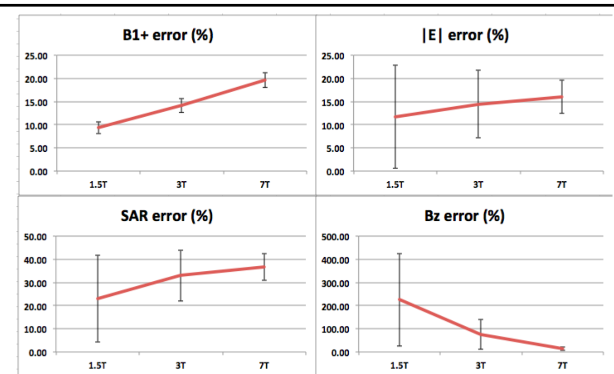

Figure 3. B_0 field dependency of the error between the original and altered surface coil simulations. Red - mean error between the simulations. Black bars - /+ standard deviation of the error.

Discussion and Conclusion: This works utilizes numerical simulation software to show that local SAR distribution changes when a simulated coil setup does not match exactly the true coil used. In the case of an "inaccurate" coil design, differences in the current density might occur between simulation and experiment. Since there is no way of using simulation to truly track the current density generated by the coil in the scanner room, these errors might be difficult to prevent. Even though the E fields and B fields are coupled via Maxwell's equations[3], the B field components are not readily known and quantifiable unless making certain assumptions regarding the coil structure and the fields it produces (such as in the case of a birdcage) and therefore it is difficult to predict how changes in the B field would effect the E field and vice versa. In the specific example presented, the mean E and SAR error between the original and altered simulation (figure 3) increase as a function of the field strength, suggesting possible drawbacks when over-relying on simulation software with hypothetical setups to account for safety of physical coils at ultra high field strengths.

References: 1.IEC 60601-2-33 (2002). 2. IEC. 62209-1 (2005). 3 Jackson, J. D. Classical Electrodynamics. 3rd edition (1998)