Numerical Considerations for Calculating SAR, Power Deposition, and B1 Field in Ultra High Field Whole-Body Full-Wave Simulations

R. Abraham[1], T. S. Ibrahim[1]

[1]Electrical and Computer Engineering, University of Oklahoma, Norman, OK, United States

Introduction: Computational electromagnetics (CEM) has become an essential tool for designing and evaluating the performance of RF coils [1-3], particularly high field coils. Due to its versatility and ease, the finite difference time domain (FDTD) method in particular has flourished in many of these types of simulations, especially in high field head and whole body applications. In this work, we provide a road map as well as considerations for using FDTD simulations to obtain accurate calculations of the specific absorption rate (SAR), power absorption, and B_1^+ (excite) field distributions in whole-body loaded volume coils operating at ultra high field 7 Tesla (300 MHz for proton imaging).

Methods: A whole-body TEM resonator structure [4] was simulated using the FDTD method, while loaded with five variations of an original full body model (obtained from the Visible Human Project), each model consisting of a different number of cells in the direction orthogonal to the axial plane. In each case, the coil was tuned to approx. 300 MHz, with the corresponding body model loaded in the coil. The lengths of the different body models are provided in Table 1. Note that the portion of the body that was loaded in the coil was constant at all cases, while the body portion extending outside the coil varied for each case, as shown in Figure 1.

Results and Discussion: All five body models were individually loaded and simulated in the same TEM resonator, excited from the same drive port (the port directly in front of the anterior of the body). Then, various parameters related to power deposition, SAR, and B_1^+ field distribution within the body models were determined. The calculated parameters are: (1) the maximum SAR for 1 Watt absorption in the body, (2) the ratio of the power absorbed in the region of the body enclosed by the coil (plus 3 cm additionally from the top and bottom of the coil) to the power absorbed in the entire body (hereafter referred to as "power ratio"), (3) SAR distribution in a central axial slice, (4) the B_1^+ field distribution in this slice, as well the standard deviation and average value corresponding to the B_1^+ field in the slice. Note that (1) and (2) are documented in Table 1 and (3) and (4) are documented in Figure 2.

From Table 1 and Figure 2, it is clear that there is a drastic difference in all calculated parameters between the smallest body model (Size 5) and the largest body model (Size 1). For example, the calculated maximum SAR, which occurred in the body near the top of the excited strut, in Size 5 was over nine times larger than that calculated in Size 1. Also note the significant difference in both the SAR and B_1^+ field distributions in the axial slice between Size 5 and Size 1 in Figure 2. The discrepancy between the calculations for the two cases is clearly due to neglecting the interactions between the drive port and much of the tissue in the full-sized body mesh in the Size 5 simulation. Interestingly, however, the second largest body model provided nearly the same values that the largest body model provided for all calculated parameters. Both the difference in the maximum measured SAR and the difference in the power ratio between Size 1 and 2 were less than 5% apart. Note that while Table 1 shows that a significant portion of the total power absorbed in the body is absorbed outside the coil, the second largest body model was sufficiently long enough to accurately predict this behavior. Also, note the similarity between the SAR and B_1^+ field distributions between Size 1 and Size 2 in Figure 2.

From this analysis, it is concluded that a length of the loaded body model approximately equal to the twice the length of the coil is needed to be present outside the coil structure above and below the coil (as in Size 2) in ultra high field computational electromagnetic simulations in order to accurately predict SAR, power absorption, and B_1^+ field.

Table 1: Length of body model, maximum SAR in the body, and ratio of the power absorbed in the region of the body surrounded by the coil (plus 3 cm additionally from the top and bottom of the coil) to the power absorbed in the entire body (denoted "Power Ratio" in table).

Length of the Loaded Body Model	Max SAR for 1 Watt Input	Power Ratio
Size 1 (125.4 cm)	1.22	0.46
Size 2 (85.8 cm)	1.28	0.44
Size 3 (61.8 cm)	1.03	0.45
Size 4 (43.8 cm)	0.89	0.64
Size 5 (25.8 cm)	11.18	1.00

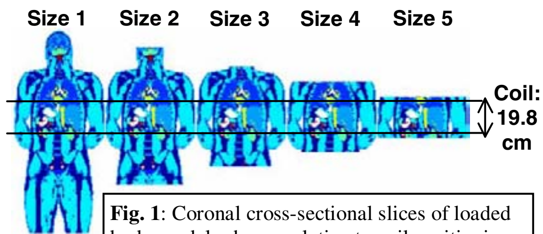

Fig. 1: Coronal cross-sectional slices of loaded body models shown relative to coil positioning.

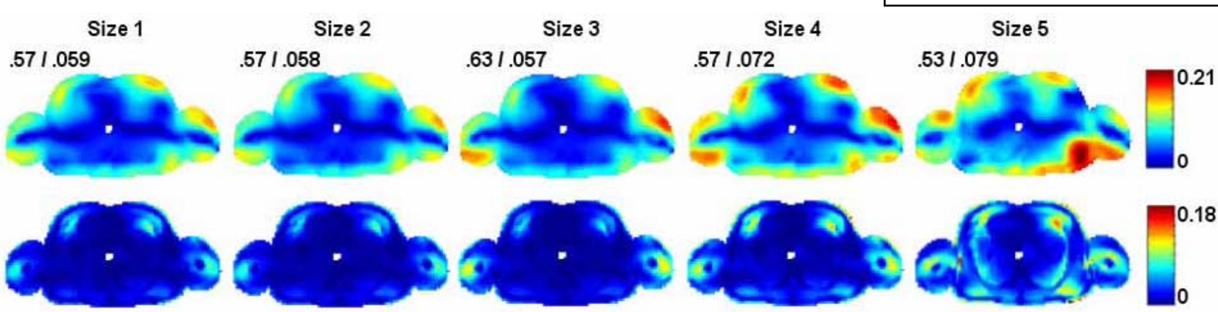

Fig. 2: *Top Row*: FDTD calculated B_1^+ field distribution (given in micro Tesla) through a central axial slice of the loaded body model, corresponding to 1 Watt absorbed power. Above each slice, the standard deviation (to examine homogeneity within the slice) followed by the average value (in micro Tesla) of the B_1^+ field is given. *Bottom Row*: SAR (Watts/Kg) distribution through central axial slice corresponding to 1 Watt input power. In both rows, the length of the anatomically detailed human body load is decreasing from Size 1 to Size 5 (see Table 1), while the position of the coil remained constant with respect to loaded region, as shown in Figure 1. The coil was tuned to approx. 300 MHz for 7 Tesla imaging.

References

[1] Collins C.M. and Smith M.B. *Magn. Reson. Med.*, vol. 45, pp. 684.691, 2001.
[2] Jin J.M., et al. *Phys. Med. Biol.*, vol. 41, pp. 2719-2738, 1996.
[3] Ibrahim, T.S., et al. *Magn .Reson. Med.*, vol 54, pp 683-690, 2005.
[4] Vaughan, J.T., et al. *Magn .Reson. Med.,* vol 32, pp 206-218, 1994.