How Much Does Coil Geometry Matter in High-Field Brain Imaging? A Numerical Study with High-Fidelity Coil Modeling

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Introduction: Transmit coil design at high-field is challenging due to the increasing B_1 in-homogeneity and SAR. Both designs with independently controlled elements and non-conventional birdcage-like coils have been proposed [1][2]. The latter has the advantage of simplicity and the ease of manufacturing. However, the effects of applying different volumetric coil patterns have not been careful studied due to the lack of modeling accuracy of the popular Finite-Difference Time-Domain (FDTD) method. Here, we applied a newly developed high-fidelity full-wave simulation software package to study such effects on both B_1 homogeneity and SAR.

Methods: The Time-Domain Finite-Difference/Finite-Element (TD-FD/FE) hybrid method was applied [3]. It utilizes unstructured tetrahedral meshes and the FEM to exactly model curved coil structures. Structured Yee's cells and the FDTD method are applied to model human phantom. Although phantoms can be modeled by unstructured tetrahedral mesh as well, most human models are voxel-based and Yee cells are more common in practice. Four 10.5-in tall shielded 16-rung volumetric coils are considered. The cross-sections of two coils are circular with 12-in diameters. Other two coils are elliptically shaped with a major axis length of 12-in and a minor axis length of 8.9-in. The elliptical cross-sections are conformal to the numerical head model being used. The rungs of each coil are either straight or twisted in the left-hand sense. Twisting is enforced in such a way that the upper ending point of each rung is 90 degree to the left with respect to the lower starting point. All copper traces are 0.4–in wide. Either elliptical or circular shield was applied conformably to each coil with the distance to the coil being kept to 1-in. A 3x3x3 mm^3 realistic human model (NLM's Visual Man Project) was applied. Each coil is numerically tuned with the phantom, so that Mode 1 is at 298 MHz. All coils were driven with 4-port circularly polarized excitations.

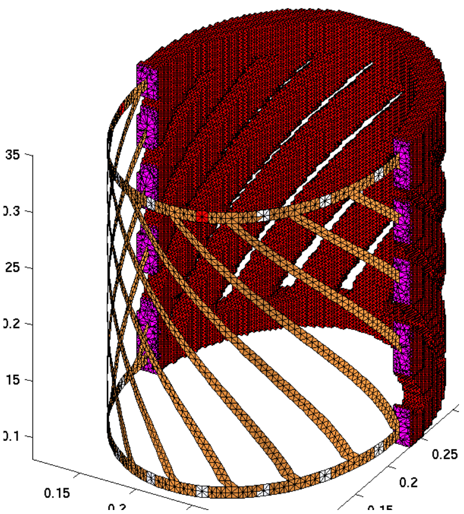

Fig 1: The twisted elliptical birdcage coil.

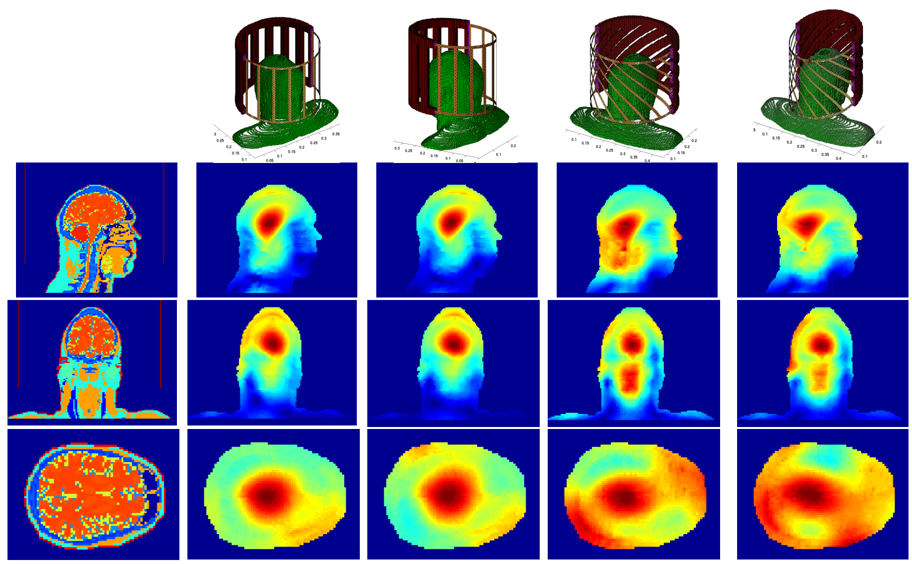

Fig 2: B_1 maps calculated by the TD-FD/FE hybrid method.

Results and Discussion: Figure 1 illustrates the finite-element model of the twisted elliptical birdcage coil. Pink color denotes the cross-sectional view of the tetrahedral mesh. Gray color on the coil represents tuning capacitors. Red color denotes excitation. All coil models with the human head phantom are shown in the top row of Figure 2. The simulated B_1 maps on the sagittal, the coronal, and one of the axial slices are shown in the second, the third and the fourth rows of Figure 2. As can been seen, the peripheral B_1 field increases and the homogeneity improves significantly on all slices as one applies twisted rungs instead of straight rungs. This is clear for both circular and elliptical coils. On the other hand, B_1 homogeneity improves marginally as the cross-section changes from circles to ellipses. We noticed that changes in this situation mainly occur on axial slices. Table I summarizes the peak SAR results. As one changes straight rungs to twisted rungs, the peak SAR jumps as much as two times. However, if one changes the cross-section changes from circles to ellipses, we observed at least 25% peak SAR drop.

	Circular straight	Elliptical straight	Circular twisted	Elliptical twisted
Peak local SAR (W/Kg/W)	0.785	0.903	1.114	0.986
Peak local SAR for a 3-ms 90 degree flip angle (W/Kg)	5.26	3.96	11.03	6.88

Table 1: SAR comparison of different coils.

From these results, a strong correlation between B_1 homogeneity and rung patterns is observed. The SAR is a more sensitive issue and affected strongly by both the rung pattern and the cross-section pattern. Cross-sections that are conformal to the human head are generally helpful in reducing the peak SAR.

Conclusion: We presented a TD-FD/FE hybrid approach that simultaneous applies the FDTD and the FEM methods in a single simulation. This method is accurate and efficient in simulating the interaction between the human body and RF coils at high-field.

References: 1) Magn. Reson. Med.;37 (4):600-608 (1997) 2) Magn. Reson. Med. 40 (1):49-54 (1998) 3) Phys. Med. Biol. 53(10): 2677-2692 (2008).