A Statistical Study of Head Models for Local SAR Simulation

Yu Shao[1], Peng Zeng[2], and Shumin Wang[2]

[1]*Auburn University, Auburn, Alabama, United States,* [2]*Auburn University, Alabama, United States*

Introduction: Subject-specific local SAR analysis is critical to the safety of multi-channel transmission at high fields. In order to calculate the local SAR, subject numerical models need to be constructed at first[1]. However, highly detailed subject models may not be available because they require high-resolution images, which in turn require the local SAR problem to be solved at first place. In a previous study, it was found that three-tissue water/fat/air model is sufficiently accurate for local SAR analysis at 3 Tesla. In this study, we shall apply a statistical approach to find the appropriate simplification of head models and its accuracy for 7 Tesla imaging studies.

Methods: This problem was investigated in two steps by using a generic eight-channel loop array with the "Duke" head model. The eight loop coils circularly surround the "Duke" head. The original head model consists of 21 different tissues. Each loop was numerically tuned (by XFDTD®) to 297 MHz. In the first step, the electromagnetic field generated by the eight coils were combined in a birdcage model, i.e., with 45^o consecutive phase shift. The "Duke" head was simplified in four different ways. The first simplification is a one-tissue model without any internal structures. Its electric properties are the averaged values across the whole head. The second one is a 3-tissue model which includes the internal air, high-conductivity tissues (muscle, CSF and etc.) and low-conductivity tissues (bone, fat and etc.) The third one is a 4-tissue model in which the brain, which includes the white matter, grey matter, cerebellum and nerve, is separated out from high-conductivity tissues. The fourth one is a 5-tissue model in which fat is further separated from low-conductivity tissues. For each head model, the peak local SAR and its position were compared with those calculated with the original "Duke" head. The least-detailed model that yields reasonable prediction is selected for the second step.

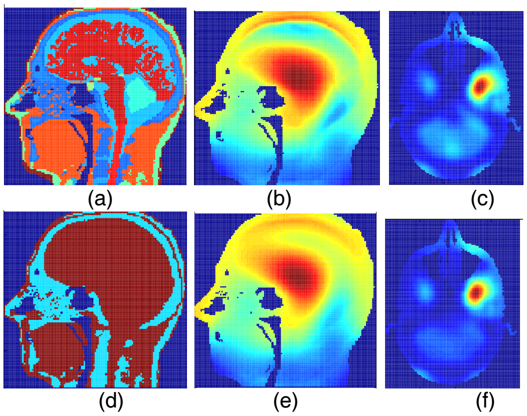

Fig. 1 (a) The original "Duke" head model. (b) B1 distribution of the birdcage mode and (c) the peak local 10-g averaged SAR in the original model. (d) The 3-tissue simplified model. (e) B1 distribution of the birdcage mode and (f) the peak local 10-g averaged SAR in the simplified model.

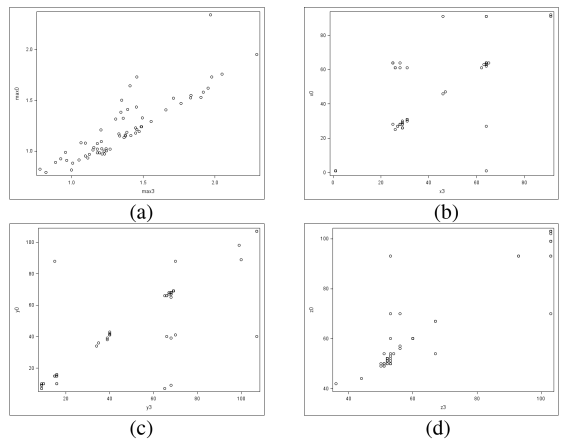

Fig. 2 The scatter plots of (a) the peak local SARs and (b,c,d) the three Cartesian coordinates of their locations between those predicted by the original "Duke" model and the 3-tissue simplified model.

In the second step, the simulated electromagnetic fields of the eight coils in the original "Duke" head model and in the appropriate simplified model found in the previous step were randomly combined by assuming uniform probability of both phases and magnitudes. This is because multi-channel transmit can be performed for different excitation goals in a fairly arbitrary fashion. Thus there were 16 random variables involved. The Latin hypercube sampling rule was used to determine the 64 sampling points[2]. The peak local SAR calculated with the original and the simplified model were fitted with linear regression. The coefficient of determination (R-square) was used to evaluate the effectiveness of the statistical model.

Results and Discussions: Figure 1 shows the original "Duke" head mode and the 3-tissue simplified model. When combined in the birdcage mode, the peak 10-g averaged local SAR in the original "Duke" model was 1.11 Watt/kg/Watt. When simplified model were applied, the combined B1 distributions did not vary appreciably. The 10-g peak local SAR was about 0.8 Watt/kg/Watt and on the posterior surface of the head when the uniform model was applied. When the 3-, 4- and 5-tissue models were applied, the locations of peak local SAR matched that predicted by the original "Duke" model. Their values were 1.32, 1.34 and 1.00 Watt/kg/Watt respectively. It was concluded that the 3-tissue model is sufficient to predict the location of peak local SAR and the 5-tissue model is more accurate.

Figure 2 shows the scatter plots of the peak local SARs and their locations between those predicted by the original "Duke" model and the 3-tissue simplified model. It was found that the peak value can be fitted by a linear regression model very well. However, the peak-SAR locations exhibit relative large discrepancies. The 4-tissue model was also examined with the same statistical approach but the results are not significantly different.

Regression model	$SAR_{\_original} = 0.09+0.83SAR_{\_3tissue}$	$X_{\_original} = 11.82 + 0.82\ X_{\_3tissue}$	$Y_{\_original} = 5.67 + 0.82\ Y_{\_3tissue}$	$Z_{\_original} = 7.63 + 0.88Z_{\_3tissue}$
R_square	0.78	0.55	0.68	0.86

Table 1. Linear regression models of the peak SAR and its location.

Conclusions: For 7T brain imaging, the 3-tissue low-conductivity/high-conductivity/air model can accurately predict both the value and the location of the peak 10-g averaged SAR in the birdcage mode. For totally random B1-shmiing, the peak SAR value can be evaluated fairly well by the 3-tissue model. However, there are incidences where the locations are less well predicted.

References: 1) Proc. ISMRM, 2010, p. 1448. 2) Iman, R.L. et.al. Journal of Quality Technology 2000: 13 (3): 174-83