VARIATIONS IN PEAK LOCAL SAR DUE TO COUPLING – COMPARISON BETWEEN VARIOUS PTX ARRAY SIMULATION METHODS

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Target: MR Safety Researchers and researchers interested in modeling RF coils for parallel transmission and SAR calculations.

Purpose: Parallel Transmission (pTx) MRI promises more homogenous B1+ fields and enhanced images. However, it is difficult to predict the location of hotspots in pTx MRI therefore it also poses a potential safety hazard. IEC guidelines[1] state that to ensure subjects' safety, precise modeling of pTx array and calculation of EM fields and SAR values are essential. Variations between the simulation model and experimental setup and a strong coupling between the channels of MR pTx array make it difficult to match the simulation and experimental results. To overcome these problems several methods of pTx array simulation have been suggested recently[2-5]. This study compared three of the suggested methods: A) "Ideally decoupled" pTx array channels[2], B) "Coupled" pTx array channels and C) Field superposition using S-parameters[3], and calculated peak 10gm average SAR (pk-10gmAvgSAR) for 5000 random amplitude and phase combinations in two adult human models for a 4-channel pTx array coil.

Method: A shielded 4-channel semi-cylindrical human head Tx array coil (Life Services, LLC. Stillwater, MN. USA) was modeled with the "Duke[6]" (Fig 1) and "Hanako[7]" (not shown), numerical models for adult Caucasian male and adult Japanese female, respectively, in SEMCAD X v14.8 (SPEAG, Zurich, Switzerland). SEMCAD X uses the FDTD method of EM simulation. Each channel of the Tx array was modeled with five equally spaced gaps for lumped elements. The first gap of each channel was filled with two ports (50Ω edge sources), and all other gaps were filled with a single port, making 24 ports in total. With this configuration S-parameters were calculated. These S-parameters were then exported to MATLAB to calculate the optimum values of capacitors to tune and match the coil to 170.33 MHz[3]. For "ideally decoupled" and "coupled" methods each channel was re-simulated with one port and five capacitors of optimum value (i.e. 4 ports and 20 capacitors in total). For the "coupled" method each channel was simulated with other channels terminated with 50Ω resistance and for the "ideally decoupled" method each channel was simulated in isolation. E-fields for each channel from both the methods were then exported to MATLAB. For "field superposition" method, the E-fields from 24-port simulations were exported to MATLAB and were superimposed for each channel according to the algorithm described by Zhang *et al* in 2009[3]. A total of 5000 random amplitude and phase combinations (Amp-Ph combinations) were generated using a pseudorandom function. E-fields of individual channel from all the three methods were then combined using $\boldsymbol{E}_n = \sum_{k=1}^{4}(a_{k,n} \bullet exp(i\phi_{k,n}) \bullet \boldsymbol{E}_k)$, where $a_{k,n}$ is amplitude between 0 and 1, $\phi_{k,n}$ is phase between 0 to 2π, k represents the channel, n represents number of Amp-Ph combinations and $\boldsymbol{E}_n$ is the combined E-field for nth Amp-Ph combination. To calculate Avg SAR and pk-10gmAvgSAR, E-fields from each combination were imported back into SEMCAD X. Before calculating pk-10gmAvgSAR, E-fields were normalized such that for each combination the Avg SAR over Duke and Hanako's head was 3.2W/Kg.

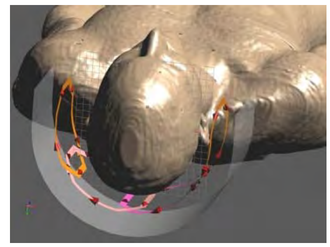

Figure 1: Shielded 4-channel human head Tx surface array coil with Duke

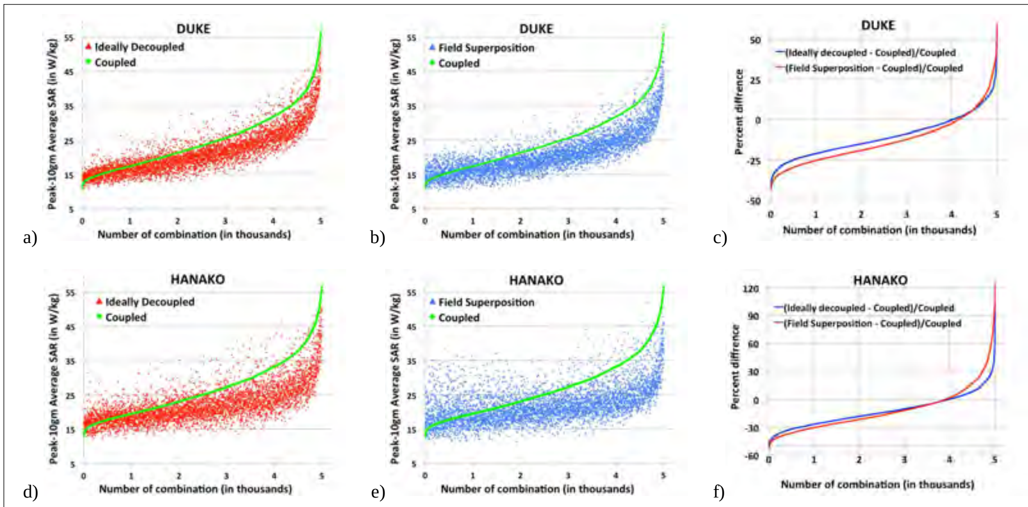

Figure 2: a), b) and c) are the results from Duke and d), e) and f) are from Hanako.

a), b), d) and e) show scatter plots of pk-10gmAvgSAR (sorted according to the values from the "coupled method").

c) and f) are the percent difference of pk-10gmAvgSAR (sorted individually).

Results: In all the three methods, with optimum values for capacitors, S_{xx} was less than -30dB with both the models. For the "coupled" and "field superposition" methods, S_{xy} was less than -11dB with Duke and -10dB with Hanako. Figure 2 (a, b, d and e) suggests that for most of the Amp-Ph combinations the pk-10gmAvgSAR is being underestimated by both the "ideally decoupled" and "field superposition" methods, however, it's not always the case. The pk-10gmAvgSAR is being over-estimated by both the methods in about 18% and 20% combinations in simulations with Duke and Hanako, respectively (Figures 2c and 2f). The summary of differences between the pk-10gmAvgSAR of the "coupled", "ideally decoupled" and "field superposition" methods is as follows:

	(Ideally decoupled – Coupled) / Coupled		(Field superposition – Coupled) / Coupled		(Field superposition – Ideally decoupled) / Ideally decoupled	
	DUKE	HANAKO	DUKE	HANAKO	DUKE	HANAKO
Maximum Under-Estimation	−41.59%	−51.342%	−43.54%	−53.20%	−37.91%	−27.32%
Maximum Over-Estimation	57.57%	102.39%	59.81%	122.72%	28.29%	95.16%
Mean	−10.38%	−12.77%	−13.10%	−12.43%	−03.00%	0.16%
Standard Deviation	12.59%	16.46%	15.00%	23.21%	9.65%	15.93%

Discussions and Conclusion: This study shows that including coupling in the simulation of pTx array is crucial for ensuring subjects safety. Since the "field superposition" method can both under- and over-estimate the pk-10gmAvgSAR, it is better to perform simulations again with optimum capacitor values being incorporated into the simulation model. While exact variations in pk-10gmAvgSAR values depend on the coil geometry and human model used, we expect the trends shown here to be more general.

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