Safety Evaluation of Algorithms to Optimize Transmit Efficiency for Local Excitation with a Transmit Array

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Introduction: Due to short wavelengths in the human body in high field MRI, achieving homogeneous RF magnetic (B_1) fields across the entire torso or abdomen for planar imaging with a transmit array is much more difficult than in the brain [1]. This has led to increased interest in advanced pulse design [2], and also in array-based optimization of the transmit efficiency on only a small region of interest rather than considering homogeneity across an entire cross-section or a large volume [3-5]. In cases where a small ROI can be used to acquire the necessary data, local B_1 shimming can provide dramatic improvements in transmit efficiency, which can translate into lower SAR, more optimum flip angles and SNR, and even increased imaging speed for SAR-limited sequences. Previously, a local B_1 shimming method with phase adjustment only at a single location was presented [3]. Recently, methods have been presented which find both phases and amplitudes that maximize transmit efficiency [4, 5]. These methods naturally minimize whole-body SAR for a given B_1 magnitude in the ROI, but with no attention to local SAR. Here we use the solution for weakly-coupled coils [4] to analyze overall safety (i.e., both local SAR and temperature for whole-body SAR at the limit) for two different ROIs in a body-sized transmit array.

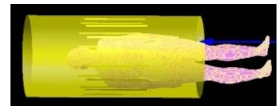

Figure 1. Model used for Numerical simulations.

Method: The B_1 and E field distributions for each individual coil of a transmit array operating at a frequency of 300 MHz (Figure 1) were calculated using commercial software XFDTD (Remcom, Inc.) and the results were processed in Matlab (The Mathworks). If $B_{1,i}^+$ is the circularly polarized component of the magnetic field generated by the ith wire at the location of interest when driven with unit current, the optimized relative current for the i-th element is assumed equal to $I_i = CA_i e^{-j\angle B_{1,i}^+}$ (eq. 1) where C is a scaling factor equal for all the elements of the array and A_i are the amplitudes that provide maximum transmit efficiency. In [4] it was demonstrated that the optimum solution of the amplitudes of the currents is equal to $A_i = \frac{|B_{1,i}^+|}{Re\{Z_{ii}\}}$ (eq. 2) for the case of an array of weakly-coupled elements.

Since the amplitudes A_i in eq. 2 are proportional to the amplitude of the $B_{1,i}^+$ field in the ROI, we can state that if the ROI is close to the center of symmetry of the subject all the amplitudes of the elements of the array A_i will be similar, while on the contrary, if the ROI is far from the center of symmetry and close to the extremities, only a few elements will have a considerable current amplitude, mainly the elements close to the ROI. If the ROI is close to the extremities the power will be concentrated in few elements of the array, which may lead to local SAR and temperature enhancement.

Results: The 10g average SAR and the temperature distribution have been computed for the transmit array system in Fig. 1 for two ROIs, one close to the heart and one close to the shoulder. The field distribution has been obtained by driving the transmit array with three different algorithms: 1) the quadrature birdcage coil, 2) the phase only optimization algorithm, 3) the both phase and amplitudes optimization algorithm. All the currents of the three algorithms have been normalized so that the whole-body SAR is equal to upper limit allowable from the IEC normal mode limits: 2 W/kg. The results in Table 1 show that regardless of driving strategy, local SAR and temperature limits for normal operating mode (20W/kg and 39°C, respectively) will be exceeded when the array is driven to the whole-body SAR limit. Greatest excesses occur when both magnitude and phase are varied. However, in cases where insufficient power is available to reach the SAR limits (as is the case with many current 7T transmit array systems) these methods should maximize the utility of the array.

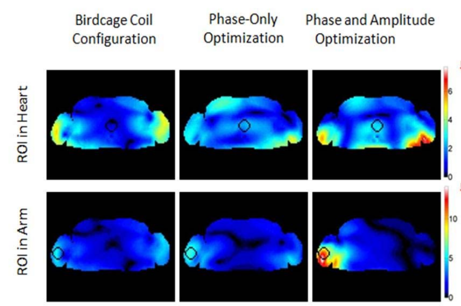

Figure 2: B_1 spatial distribution of three different algorithms driving an 8ch transmit array with two different ROI optimized. The fields are normalized so that the whole-body SAR is equal to 2 W/kg

	ROI in Heart		ROI in Arm	
	Max 10g local SAR (W/Kg)	Max temperature (C∘)	Max 10g local SAR (W/Kg)	Max temperature (C∘)
Birdcage	28.70	41.65	28.70	41.65
Phase-only Optimization	34.19	40.12	40.49	40.16
Optimization with phase and amplitude	59.60	40.53	165.46	52.02

Table 1: Maximum 10g local SAR and temperature obtained with the application of three different current distributions including optimizations for an ROI near the heart and in the shoulder. In each case whole-body average SAR is 2 W/Kg.

References

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