Array-optimized Composite Excitation Pulse for Simultaneous Homogenous Excitation and Low SAR in a Human-Body Transmit-Array at 3.0T

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Introduction: In high-field MR imaging, B_1 homogeneity is degraded by wave behavior and penetration effects. These effects are very significant in human-body imaging due to the large sample size. Recently, several techniques have been proposed to improve the excitation homogeneity in high-field MRI, including RF-shimming [1], transmit SENSE [2], and optimization of composite pulses using transmit coil arrays [3]. However, generally, if the excitation homogeneity is improved then the specific absorption ratio (SAR) may also increase, so homogeneity and SAR should be considered simultaneously during optimization [4]. In this numerical study, a composite RF pulse is designed to simultaneously improve the excitation homogeneity within the human body and reduce the peak SAR. The composite RF pulse can achieve both significantly better excitation homogeneity and significantly lower SAR levels than are possible with RF shimming alone.

Method: A 16-element whole-body transmit array coil was modeled at 128MHz (3.0T) using xFDTD software (Remcom, USA) with a three-dimensional isometric grid (5×5×5mm^3) as shown in figure 1. The matrix size is 199×199×492 in *x*, *y*, and *z* direction, respectively. Current sources were placed at each end of each element. The human-body model, containing 36 different tissues, was loaded in the body coil array. A composite pulse comprised of two consecutive RF pulses with individually-optimized field distributions is employed to enhance the excitation homogeneity. Optimization considered 64 variables for composite pulses (magnitude and phase for 16 elements in each of 2 pulses) or 32 variables for RF shimming (magnitude and phase for 16 elements in 1 pulse) with the aim of maximizing the excitation homogeneity and minimize the peak SAR using a home-built optimization routine based on MATLAB (Mathworks, USA). For each iteration step, the mean and standard deviation (STD) of the transverse magnetization vector (M_t) were examined to evaluate the B_1 homogeneity. Theoretically, the mean M_t should be 1 if the B_1 field distribution is perfect (flip angle equal 90° everywhere). Simultaneously, the maximum SAR was also calculated for an entire human-body to reduce the peak SAR. A simple weighting function (η×inhomogeneity + (1-η)×SAR$_{max}$, η:0~1) was employed to consider both excitation homogeneity and the peak SAR, simultaneously [5]. When η=1 the optimization of the excitation homogeneity occurs without consideration of SAR, while η=0 results in optimization of SAR without consideration of excitation homogeneity. The RF pulse duration of the RF-shimming pulse and the entire composite RF pulses were both 3ms.

Results and Discussion: Figure 2 shows the M_t and SAR (W/kg) distributions of the RF-shimming and the array-optimized composite pulse for weighting factor η of 1.0 and 0.6. Globally, the array-optimized composite RF pulse shows better excitation homogeneity and SAR than the simple RF-shimming. The mean M_t and SAR values are summarized in table 1. In the table, the average and maximum SAR values were calculated in the entire human-body model. As expected, lower mean M_t and maximum SAR values were observed when the lower weighting factors were used for both RF-shimming and the array-optimized composite pulse. With no consideration of SAR (η=1.0), the mean M_t is close to 1 which means close to 90° flip angle throughout the plane for the array-optimized composite pulse (not shown), whereas RF-shimming shows M_t=0.9718. When the weighting factor is decreased (η=0.6), the mean M_t for the optimized composite pulse is still better than the RF-shimming for η=1.0. If the homogeneity (STD) is identical between RF-shimming and array-optimized composite pulse (not shown), the array-optimized composite pulse shows a higher mean M_t, slightly lower average SAR, and significantly lower (by about 50%) maximum SAR than RF-shimming. Homogeneous excitation considering SAR with weighting factors is thus potentially very valuable for high-field MRI. While even greater flexibility could be expected for fully-parallel transmit SENSE-type pulses than seen here for a simple 2-pulse composite, slice selection and large flip angles are more readily accomplished for composite pulses.

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References:

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[3] Collins *et al.* Magn Reson in Med 2007;57:470-474
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	η	RF-Shimming		Composite Pulse	
M_t	1.0	Mean	0.9718	Mean	0.9932
		STD	0.0312	STD	0.0081
	0.6	Mean	0.9392	Mean	0.9745
		STD	0.0515	STD	0.0302
SAR [W/kg]	1.0	Avg.	4.1321	Avg.	4.1385
		Max.	294.28	Max.	205.04
	0.6	Avg.	4.1233	Avg.	4.1154
		Max.	224.27	Max.	112.57

Table 1 The mean transverse magnetization (M_t), standard deviation of M_t, and SAR (W/kg) are shown. The average and maximum SAR are calculated for the entire human-body model.

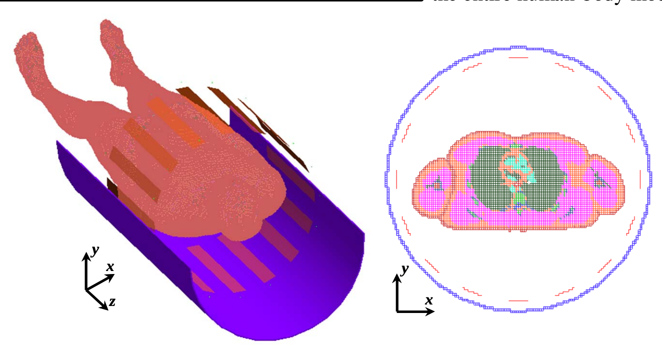

Figure 1 The geometry of the 16-element transmit array coil (left, half of the RF-shield was removed for better view) and one axial plane (right). The diameters of RF-shield and coil are 690 and 630 mm, respectively. The length and width of each element are 500mm and 50 mm, respectively. The length of RF-shield is 1400 mm.

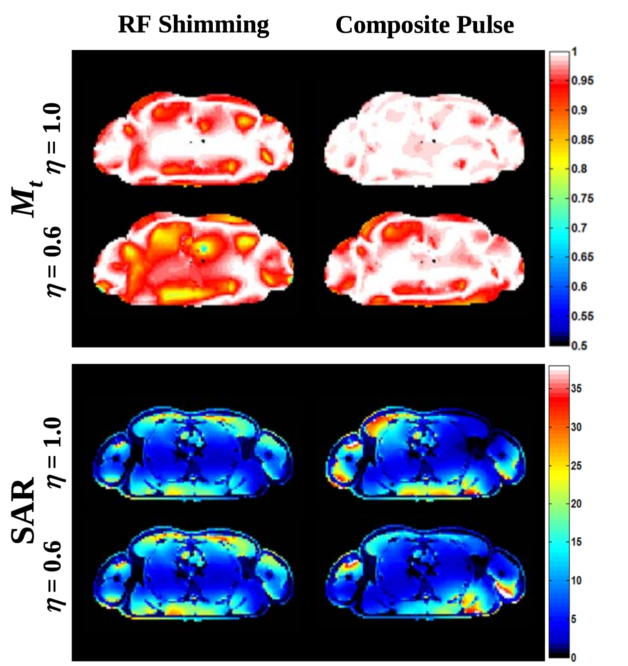

Figure 2 M_t and SAR (W/kg) for RF-shimming (left) and array-optimized composite pulses (right) without consideration of SAR (η=1.0) and with consideration of SAR (η=0.6) on an axial slice through the heart. When η=0.6, both better excitation homogeneity and lower SAR can be observed with the composite pulse.