Slice-Selective Array-Optimized Composite Pulse for Simultaneous Improvement in Excitation Uniformity and Reduction of SAR

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INTRODUCTION: A number of groups have introduced a variety of methods using transmit arrays to simultaneously improve excitation homogeneity and reduce SAR (1-8). Some methods are limited to low flip angles and/or long pulse durations, some present challenges for slice-selective implementation, and some (those relying only on RF shimming) are limited by what can be accomplished within the bounds of the Maxwell equations for excitation uniformity. In this work, a slice-selective two-pulse array-optimized composite pulse considering both B_1 uniformity and SAR with a simple cost function is designed and compared with the conventional quadrature driving method. To implement our simulation result, MR images are acquired using a 3D MRI simulator (implementing the Bloch equations in 3D with no small-tip approximations) currently under development.

METHOD: An 8 channel transmit array having an inner diameter of 246 mm, and a length of 214 mm and loaded with a human head was simulated at 128 MHz (3T) (Fig. 1). An 8-element quadrature birdcage coil having similar geometry was simulated for comparison. A human head model having 23 different tissue types with a 2 mm resolution was used. The FDTD method was used to calculate the B_1 and electric field (E-field) produced by each element driven individually. Then current magnitudes and phases in both component pulses were optimized to produce the most homogeneous transverse magnetization (M_t) at the end of the second component pulse and the lowest SAR throughout the pulse. During optimization, a simple cost function (5), $\eta \times$inhomogeneity + $(1-\eta)\times$SAR, $0 \le \eta \le 1$, was minimized. All FDTD calculations were performed using commercially available software (xFDTD; Remcom, Inc; State College, PA). Optimization was performed using hole-built code in Matlab (The MathWorks, Inc., Natick, MA). After optimization, amplitudes and phases of optimized currents for each channel were used to acquire MR images using a Bloch-equation-based MR Simulator with all pertinent information (e.g., T_1, T_2 and proton density tissues, head geometry, B_1 distribution of each coil element, and pulse sequence for all RF and gradient coils). The excitation uniformity was estimated using a proton density-weighted image having parameters of TR = 2000 ms, TE = 20 ms and gradient echo sequence.

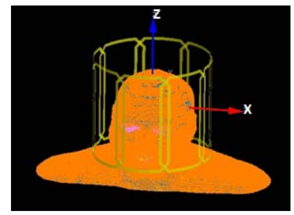

Figure 1 Geometry of transmit array and head model.

RESULTS: Fig.2 shows the distribution of SAR and M_t for the quadrature birdcage coil (BC) (first column) and the 8 channel transmit array before (second column) and after (third column) optimization throughout the selected axial slice at 128MHz. The Optimized composite pulse has better performance both in excitation uniformity and SAR compared to quadrature birdcage. When η was increased from 0 to 1, the excitation uniformity calculated by the standard deviation of M_t was improved whereas mean value of SAR was increased. A good compromise was seen when η was 0.45 (Fig. 2). Fig. 3 shows the designed pulse sequence for the optimized composite pulse and the acquired proton density weighted images acquired with and without the slice selection gradient. To evaluate the excitation uniformity of the single slice image acquired by the optimized composite pulse and conventional quadrature birdcage, we assigned T_1, T_2 and proton density of all tissues identical values. The resulting signal intensity distribution on a 2D axial plane and 1D line in the left-right direction using this head model are shown in Fig. 4. Results show that the array-optimized composite pulse has better excitation uniformity than that of quadrature birdcage.

DISCUSSION: It has previously been shown that a simple 2-pulse array-optimized composite pulse can provide homogeneous excitation over the entire brain at up to 600 MHz (9), and perform much better than RF shimming in improving homogeneity (9) or in simultaneously improving homogeneity and reducing SAR (8). Here we have demonstrated slice selection with a similar pulse and implemented it on a 3D MRI simulator using coil geometries and a frequency that will facilitate experimental implementation as well. While the simulator has no limitation in slew rate so the slice-selective pulse with rectangular gradient waveforms could be as short as desired, in experimental implementation triangular gradient waveforms and the VERSE technique could be used to minimize pulse duration (10). As shown here, the image and profile acquired using the optimized composite pulse has better excitation uniformity (Fig. 4) and lower SAR (Fig. 2) than the quadrature birdcage. Thus, pulse duration can be very short, slice selection is possible, there is no limitation to low flip angles, and both SAR and excitation uniformity can be improved with the array-optimized composite pulse in the head at 3T, currently a clinically-relevant setting.

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REFERENCES

1. van den Berg *et al.*, ISMRM 2006; p2040
2. Wu *et al.*, ISMRM 2007; p673
3. Graesslin *et al.*, ISMRM 2007; p674
4. Ibrahim *et al.*, ISMRM 2007; p1013
5. Wang *et al.*, ISMRM 2007; p1022
6. McKinnon, ISMRM 2007; p1085
7. Zelinski *et al.*, ISMRM 2007; p1699
8. Oh *et al.*, ISMRM 2008; p1309
9. Collins *et al.*, MRM 2007; 57:470-474
10. Sung and Nayak, MRM 2008;59:441-446

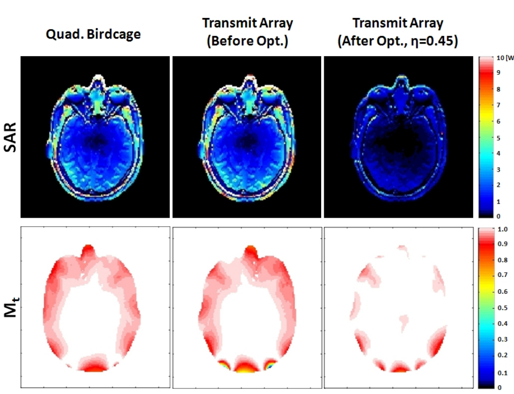

Figure 2 Distribution of SAR and M_t predicted during optimization throughout the selected slice of a head at 128MHz (3T) for quadrature birdcage coil (first column), and transmit array with composite pulse before (second column) and after (third column) optimization.

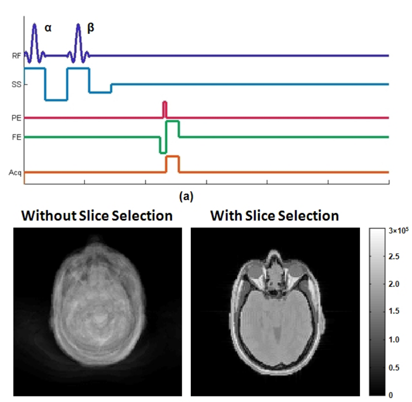

Figure 3 Pulse sequence for the optimized composite (top) and proton density weighted images acquired with and without a slice selection gradient (bottom). Slice thickness is 2mm. (Image without slice selection shows signal from entire head model).

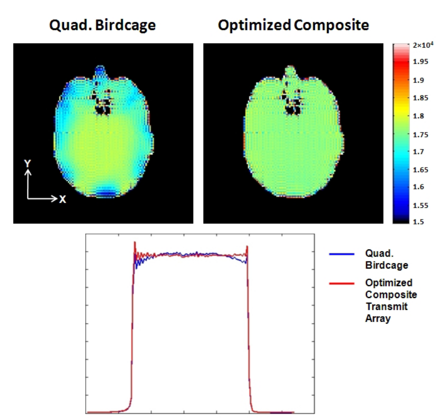

Figure 4 Signal intensity on axial plane (top) and central left-right line (bottom) of quadrature drive and optimized composite pulse using a head model with all tissues having identical T_1, T_2, and proton density in a 3D MRI simulator at 3T.