Array-optimized Composite Pulse for Homogeneous Whole-Brain Inversion in High Field MRI

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Introduction: Radiofrequency (RF) pulses inducing 180° flip angles are used in inversion and in the creation of spin echoes. Provided that the flip angle in the volume of interest is very homogeneous, these pulses can be used effectively in accurate quantitations of T_1, T_2, and many other related parameters. They are also essential components of many standard clinical and experimental sequences, facilitating tissue-selective signal suppression, perfusion imaging, and rapid image acquisition. However, the homogeneity of the RF field decreases as the main magnetic field strength increases. One method of compensating for RF inhomogeneity is with the use of specific composite pulses [1]. Here we show that by combining the concept of the composite pulse with that of the transmit array to create a sequence of pulses with different field distributions [2], it is possible to produce extremely homogeneous inversions in the entire human brain at very high frequencies.

Method: RF field calculations were performed in a human head model for each element in a 16-element coil array (Figure 1) at 300 and 600MHz. For these calculations, we used commercial software (XFDTD, Remcom, USA) and a three-dimensional isometric grid with 5mm spacing. After calculating the RF magnetic field (B_1^+) [3], we optimized the magnitudes and the phases of the driving current sources of each coil elements using home-built optimization routine based on MATLAB (The Mathworks ver. 2006a, USA). Three different inversion pulses were compared: 1) a single pulse that was RF-shimmed [4] to produce a homogeneous inversion, 2) a composite pulse consisting of 3 RF pulses (90x-180y-90x) using the same field distribution (coil driving configuration) as in the single pulse, and 3) a composite pulse where the driving currents in each element in each of the three pulses were optimized to produce a homogeneous inversion. We examined the longitudinal component of the magnetization vector, M_z, using the mean and standard deviation of M_z in the whole brain area after the optimized composite inversion RF pulse was applied. An M_z of -1.0 means the flip angles are exactly 180° (inversed flip angle from the initial status) from the orientation of the main magnetic field. Also, we compared the average Specific Absorption Rate (SAR) of the three different pulses [5].

Results: Figure 2 shows the values of M_z through the center axial plane in the brain for all three pulses at both 300MHz and 600MHz. First, we calculated the magnitude of M_z when we applied single inversion RF pulse. At both frequencies, the 90x-180y-90x application of the shimmed field distribution shows an improvement over the single-pulse application, but the result of the optimized composite pulse with different field distributions in each pulse is superior to both. For this last case the mean value of M_z is very close to -1 (-0.998) at 300MHz, indicating a mean flip angle of very nearly 180°. The average SAR values for all three pulses at both 300MHz and 600MHz are shown in table 1. While the final optimization is seen to increase SAR, future work using optimization routines that also consider SAR may alleviate this effect with little cost to homogeneity.

Table 1. The SAR averaged over the head for all inversion pulses assuming they are applied over 200ms with a pulse duration of 3ms for each pulse (i.e., 3ms for each component of the composite pulses).

	SAR (W/kg)		
	Single	Composite	Optimized composite
300MHz	0.352	0.528	1.188
600MHz	0.732	1.099	2.239

Discussion: This study shows a precise inversion RF pulsing technique using a numerically optimized composite pulse in a whole human brain for high field MRI. When we applied the conventional composite pulse with an RF-shimmed field distribution, the mean M_z already reached below -0.98 at 300MHz. This shows the importance about the composite pulse for precise T1 measurements or signal suppressions. However, the standard deviations are still higher than with the optimized composite pulse (11 times at 300MHz). Still, imperfections are visible with the array-optimized composite pulse at 600MHz with M_z values were around -0.75. While this is still an impressive result for whole-brain inversion at 600 MHz, it may be possible to further improve the results with different kinds of global optimization techniques, such as genetic algorithms or simulated annealing.

References:

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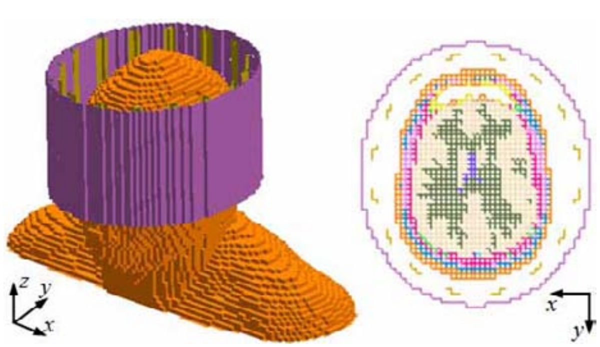

Figure 1. The geometry of the numerical human head model with shielded 16-element coil array. One axial plane is shown on the right.

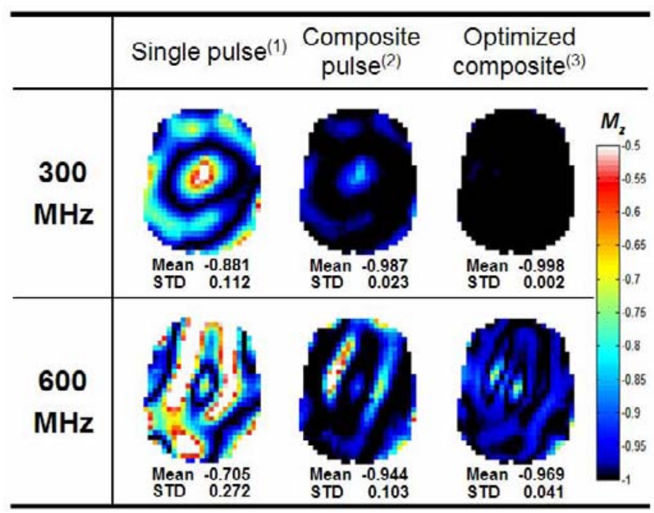

Figure 2. Values of M_z on the center axial plane through the brain for three different pulse types including single-pulse inversion with an RF-shimmed field (left), a conventional composite inversion pulse using the RF-shimmed field (center), and an array-optimized composite inversion pulse (right).