Bloch Simulation of Human MR Imaging at 14T

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Introduction: In preparation for a 14T head-only system planned for installation in Incheon, South Korea, we have performed some numerical examinations of potential challenges, benefits, and hazards at this field strength, particularly RF transmit homogeneity, image homogeneity, SNR, and SAR at 14T as compared to 7T and 3T.

Method: All simulation studies were performed using a Bloch-based MRI simulator [1] able to calculate realistic MR signal, noise, and unaveraged SAR with multichannel transmission and reception. A 2mm resolution human digital phantom (including proton density, T_1, and T_2 values appropriate for 3T) was input into the Bloch simulator with associated RF electromagnetic fields, pre-calculated for an eight channel transmit and receive volume coil model (Fig.1) using the FDTD method with commercially available software (XFDTD; Remcom Inc, State College, USA). Appropriate circularly-polarized components (B_1^+ and B_1^-) for the transmit (Tx) and receive (Rx) RF magnetic fields were derived from the FDTD results for use in the simulator. The B_0 field distribution was performed within the MRI simulator with a method based on a previously published method [2]. In this work gradient echo sequences with varying TEs and different combinations of Tx and Rx RF fields were simulated as follows:

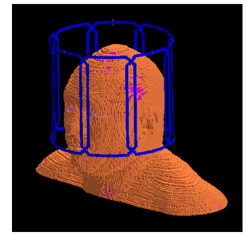

Figure 1. Head phantom with eight channel Tx/Rx array.

1) Study of image inhomogeneity as for a Tx/Rx volume coil: The eight channel Tx/Rx coils were first combined as a volume coil in quadrature to simulate the well-known center-bright artifacts and establish a baseline for further studies. In addition, to demonstrate the increase of T_2^* effects at increasing main magnetic field strength, the gradient echo sequences that were generated were identical for these three different field strengths scenarios (TE/TR=3/500ms, BW=200kHz, FOV=300x300cm, image resolution=128x128, slice thickness=6mm, flip angle=90).

2) Study of image inhomogeneity with RF shimming: To evaluate the Tx field homogeneity achievable at each field strength, the magnitude and phase of current in each coil to produce optimal Tx field homogeneity were calculated by using an in-house RF shimming routine and were input into the Bloch simulator. To demonstrate the Tx homogeneity achieved, the simulations were first performed assuming a homogeneous Rx field distribution. Then they were repeated with realistic Rx field distributions as described at the end of this section. All simulations were performed with similar GRE sequence (TR=500ms, BW=200kHz, FOV=300x300cm, image resolution=128x128, slice thickness=6mm, flip angle=90), except for TEs which were inversely proportional to field strength (TE=9.33/4/2ms for 3/7/14T respectively).

3) Study of SNR: The image SNR was evaluated by acquiring 50 images with the similar sequence protocol as in 2) except with the same TE=2ms for different field strengths for fair SNR comparison. SNR maps were generated by calculating the mean and standard deviation of each image pixel through the 50 images.

4) Study of SAR: The sequence-specific unaveraged SAR generated by the Bloch simulator was processed with an in-house calculator for 10g-SAR distribution [3]. Maximum 10g SAR and whole head averaged SAR were recorded to represent the amount of RF heating from the transmit volume coil into the human head phantom based on a gradient echo sequence with TR=500ms and flip angle=90.

Important details of the above simulations: 1) Definition of 90° transmit flip angle: For fair comparison of the above field inhomogeneity, SNR and SAR, all simulations utilized a flip angle determined with adjustment of the overall transmit voltage to maximize the overall image intensity. 2) Method for array image combination: For simulations with input B1- field distribution, fully-sampled array images were acquired and combined using adaptive combination method [4]. To overcome the receive image inhomogeneity artifact, simple postprocessing techniques were used [5].

Results & Discussion: The simulation results predict some important phenomena. As expected, with equal TE and a Tx/Rx volume coil, both B_0 and B_1 artifacts become more pronounced as field strength increases (Fig.2(a)-(c)). With RF shimming on only 8 Tx channels and shorter TE at higher field strengths, relatively good Tx field homogeneity on a single plane and mitigation of B_0 artifacts can be achieved, even at 14T (Fig.2(d)-(f)). From 3T to 7T to 14T, image SNR improves significantly (Fig.3). Importantly, SAR (Table.1) does not increase as rapidly as SNR when shimmed, especially from 7T to 14T. This demonstrates an important benefit from 7T to 14T. Although the images weighted with realistic receive field inhomogeneity for 14T (Fig.2(g)~(i)) show greater inhomogeneity at 14T, more advanced postprocessing techniques can be utilized to overcome such inhomogeneity. In future work, inclusion of field-specific relaxation properties and coils designed for the specific purpose and field strengths should give more accurate results. Nonetheless, this early investigation shows great promise for human head imaging at 14T.

References: [1] Cao *et al.*, ISMRM 2010, p1456 [2] Collins *et al.*, MRI 2002;20:413-24 [3] Oh *et al.*, ISMRM 2011, p3868
[4] Walsh *et al.*, MRM 2000;43:682–690 [5] Griswold *et al.*, ISMRM 2002, p2410

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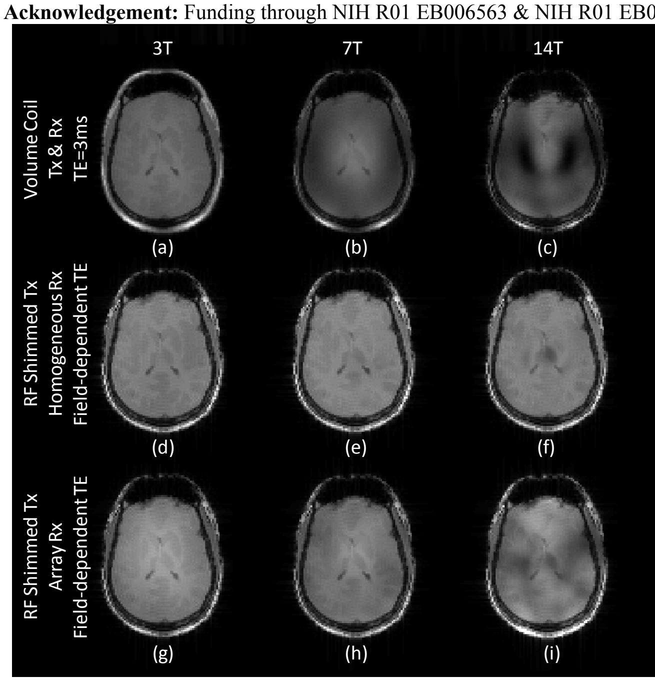

Figure 2. Simulated human brain images with different Tx/Rx fields for different field strengths.

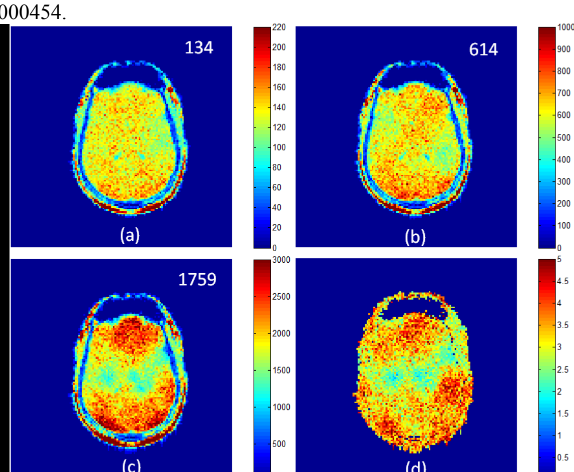

Figure 3. SNR Maps for different field strengths: (a) 3T, (b) 7T, (c) 14T. The mean SNR value of the center of the brain image is recorded at the upper right. (d) shows the SNR ratio for 14T over 7T.

		3T	7T	14T
Without RF Shimming	Whole Head Average SAR (W/kg)	0.0961	0.2657	0.6866
	Peak 10g SAR (W/kg)	0.332	1.0845	3.2321
With RF Shimming	Whole Head Average SAR (W/kg)	0.2526	0.4332	0.5004
	Peak 10g SAR (W/kg)	1.1414	1.8176	1.9459

Table 1. Whole head average SAR and peak 10g SAR for different field strengths.