Experimental Validation of FDTD Magnetic Field Modeling in the Human Head at 7T

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Introduction: Recent increases in computing power have made full-wave EM simulation software more useful for the design and verification of MR coils and coil-patient interactions, especially important at high field (e.g. 7T). A crucial step in making simulation tools a routine, trusted component of the design process is the experimental verification of simulation results. While there are challenges in the experimental measurement of some EM quantities such as E field and SAR, comparisons between the simulated and experimentally measured B_1^+ fields is an important step toward validation and confidence in the accuracy of other simulated quantities. Here we sought to perform a direct comparison between EM simulations using the FDTD approach and experimental measurements at 7T, focusing on the B_1^+ field as the parameter of study since there are new and accurate ways to measure B_1^+ efficiently over entire volumes such as the head.

Methods: The commercial FDTD package, SEMCAD X (Schmid & Partner Engineering AG, Zurich), was used to simulate the B_1^+ and E fields within a 16-rung high-pass birdcage coil loaded with the Virtual Family [1] model 'Ella' (simulating a 26 year old female, model available from the Foundation for Research on Information Technologies in Society, Zurich), for which the dielectric tissue properties were taken from Gabriel et al. [2]. The birdcage dimensions were set as follows: 305mm diameter and 207mm length for the primary, 371mm diameter and 229mm length for the shield, 0.03mm thickness, and at each end-ring gap a 5.6pF capacitor incorporating 8kΩ parallel resistance. The coil was discretized using 7 cells spanning the width of each end-ring and 15 cells spanning the width of each leg to properly resolve the geometry of the coil. The entire simulation space was discretized into approximately 23M cells. The first step of simulation was to find the uniform birdcage mode (based on maximum B_1^+ uniformity in the axial plane and minima in the S21 response using a quadrature port excitation) and to set its resonant frequency to 298MHz by adjusting capacitance. Then, B_1^+ and E fields were calculated over the head model, using single port excitations (I-only or Q-only) to provide inputs for the design of parallel transmit RF pulses and modeling of parallel transmit fields. The simulated B_1^+ fields were compared to experimental *in vivo* B_1^+ measurements, using a matched geometry high-pass birdcage head coil (Nova Medical, Wilmington MA) on a 7T MR scanner (GE Healthcare, Waukesha, WI). The B_1^+ maps were acquired using the Bloch-Siegert (B-S) B_1^+ mapping method [3], with an optimized off-resonance (1960 Hz) 4ms B-S pulse [4] with the following parameters: TR: 425ms, TE: 7.1ms, FOV: 22cm, slice thickness: 5mm, resolution: 64x64, bandwidth: 31.2 kHz.

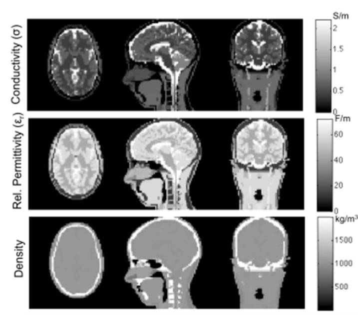

Fig 1: Brain parameters used in 'Ella' head model

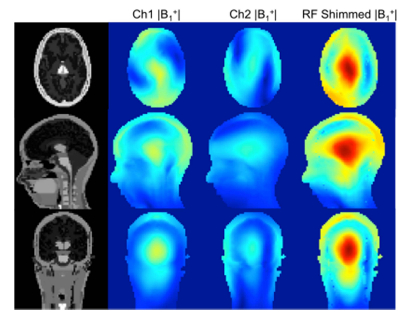

Fig 2: SEMCAD simulated magnetic fields for a quadrature driven head coil

Results: The Virtual Family model provides realistic detail of head structure and tissues, to which dielectric properties are assigned accordingly, shown in Fig 1. Simulated B_1^+ maps demonstrate strong inhomogeneity of the magnetic field with higher field values at the center of the brain, as expected. Fig 2 shows the simulated B_1^+magnetic field for the head model in the birdcage coil, driven either in single channel drive mode or in quadrature using optimal RF shim settings. In Fig 3, experimental and simulated B_1^+ fields are compared. Individual channel maps show similar patterns between experiment and simulation, both showing weaker B_1^+ fields at the edges of the head and a characteristic "pinwheel" pattern. For the RF shimmed maps, the pattern is also very similar, although the simulated map shows a slightly stronger B_1^+ field towards the center. In Fig 4, experimental and simulated B_1^+ fields are compared in a coronal plane. Although the in-vivo B_1^+ maps are noisy, the B_1^+ patterns still look very similar for both individual channel drive and RF shimmed case.

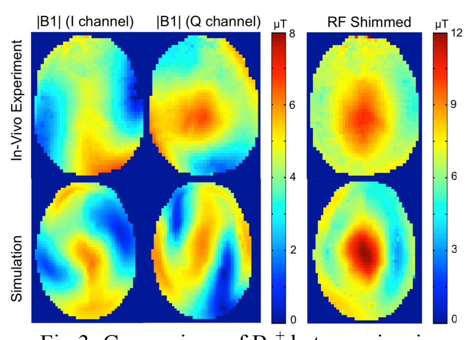

Fig 3: Comparison of B_1^+ between in-vivo and simulation in Axial plane

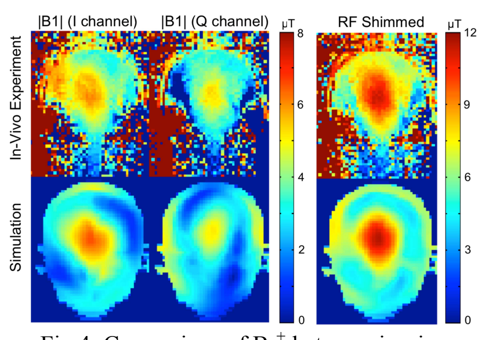

Fig 4: Comparison of B_1^+ between in-vivo and simulation in Coronal plane

Discussion: The similarity in field distributions between simulation and experiment for the individual channel drive as well as the optimized RF shim drive is strong evidence of the ability of these simulation tools to accurately predict field patterns for a quadrature driven birdcage coil. Furthermore, the excellent correspondence between simulated and experimental magnetic fields has implications for complex pulse and coil design problems. Simulations of parallel transmit pulse design can be accomplished, for example, with nearly instant feedback, allowing rapid optimization of pulse parameters. The same simulation tools will give greater insight into multi-channel transmit design, and should provide faster and cheaper methods of testing new and complex coil designs without the limitations of physical construction.

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References: [1] Christ et al., Phys. Med Biol. 55:N23–N38, 2010. [2] Gabriel et al., Phys. Med. Biol. 41 2271 [3] Sacolick et al., MRM 63:1315-1322, 2010. [4] Khalighi et al., MRM in press, 2011.