RF Shimming in an MRgFUS Brain Transducer with a High Permittivity Material

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Introduction

During MRgFUS neurosurgery, dielectric resonances occur in the integrated water bath that is required for coupling and to cool the scalp. These resonances result in heterogeneous signal intensity across the brain during MRI at 3T. High MR sensitivity near the conducting transducer surface is accompanied by low sensitivity around a half wavelength from the surface. The purpose of this work was to investigate the ability to RF shim with pads of a high permittivity material[1] so that the MR signal in the region of treatment allows for reliable temperature mapping.[2] Simulations and experiments were performed for pads of barium titanate placed outside but in contact with the water bath.

Methods

Electromagnetic simulations were performed using xFDTD (Remcom, State College, PA) using the "Hugo" whole body model. Figure 1 (b,c) shows a comparison with and without the water bath. With water, B_1^+ is enhanced in the superior part of the brain, and signal loss is apparent in the central and inferior part of the brain. These effects are due to the large displacement currents induced in the water. Inhomogeneity of the B_1^+ field is reduced by introducing barium titanate pads, which have even higher permittivity (ε_r=290), causing additional displacement currents that "pull" the magnetic field towards the inferior aspect of the brain.

For experimental validation, four parts barium titanate powder were mixed with one part water and sealed in thermoplastic bags. These were then used to shim the RF field in the InSightec ExAblate 4000 Neuro transducer inserted into a GE 3T MRI scanner. The head of a volunteer was positioned in the transducer and immobilized by resting it on a plexiglas platform attached to a stereotactic head frame. A rubber membrane was placed around the head and attached to the transducer cavity which was then filled with water. The subject was imaged with a 3-plane localizer fast GRE sequence with the following parameters: TE/TR = 1.4/4.9, FOV=42 cm, 256x128 image matrix, 7 mm slice, nominal flip angle = 30. Two conditions were studied: a) without the barium titanate pads, b) with a pad placed to the right of the subject (arrow in Figure 2b), and an additional smaller pad placed above the subject. The pads were in contact with the rubber membrane.

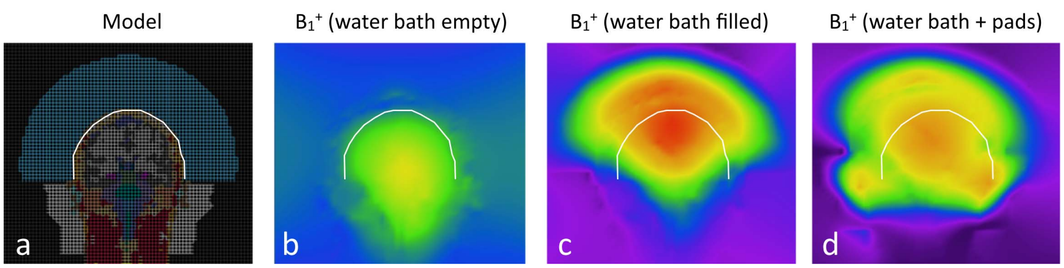

Figure 1. Electromagnetic simulations using Hugo (a) show that compared to the water bath empty (b), the water bath filled condition (c) has high signal at the top of the brain, with signal dropout lower. Added high permittivity pads "pull" the magnetic field inferiorly (d).

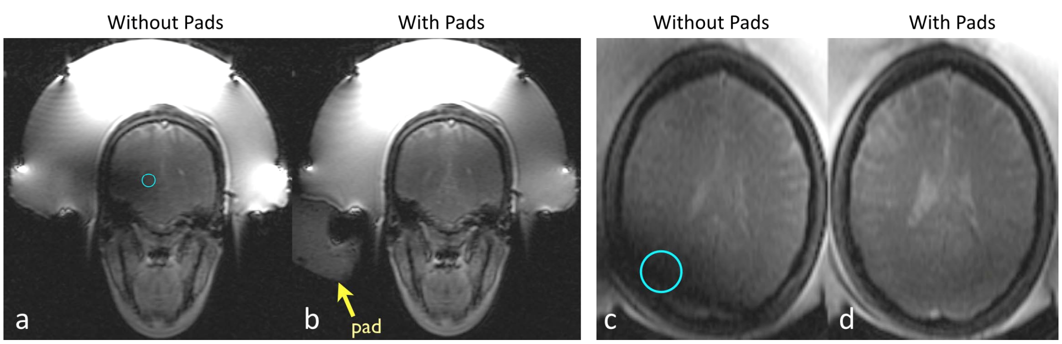

Figure 2. Coronal and axial images acquired (a,c) without and (b,d) with barium titanate high permittivity pads (arrow) placed adjacent and touching the rubber membrane. ROI locations shown demonstrate in (a) a 2-fold and in (c) a 12-fold improvement in SNR.

Results and Conclusions

As compared to the condition without the barium titanate pads, improvements in signal intensity and homogeneity were seen across the head with the pads in place. Coronal and axial images demonstrating the improvement in signal intensity are shown in Figure 2. In the area of the biggest signal dropout (ROI indicated in Figure 2c), the signal demonstrated a 12-fold improvement. Near the treatment area (ROI indicated in Figure 2a), the signal demonstrated a 2-fold improvement. The general results from the simulation and experiment are the same, although the pad placement was slightly different. In conclusion, pads of barium titanate placed appropriately at the air water interface can reduce significant signal dropouts in a resonant cavity transducer.

References 1. Haines K, Smith NB, Webb AG, J Magn Reson. 2010 Apr;203(2):323-7. 2. Rieke V, Butts Pauly K, JMRI. 2008 Feb;27(2):376-90.

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