Development of Tissue Susceptibility Matched Pyrolytic Graphite Foam for Improved Frequency Selective Fat Suppression and Motion Suppression in Breast MRI

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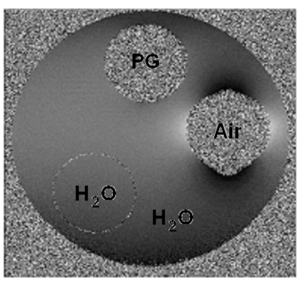
Introduction: With nearly 200,000 new cases of breast cancer diagnosed every year, breast MRI has emerged as common imaging modality for diagnosis, along with x-ray mammography. Frequency selective fat suppression methods exploit the 3.5 ppm chemical shift between fat and water to saturate the fat signal in MRI. B_0 field homogeneity must be ~1 ppm for robust frequency selective fat sat methods. Unfortunately, the field homogeneity near the skin is typically ten times worse than 1 ppm (±5 ppm) due to air near the skin. Field shimming methods cannot reliably shim out the steep field patterns induced near certain parts of the body (e.g. breast or shoulder). Here we tested pyrolytic graphite foams that match tissue susceptibility for improved frequency selective fat suppression. We also checked the foams for heating and conductivities issues for safety. In particular we are targeting robust fat suppression for contrast-enhanced breast MRI and an increase in breast MRI specificity.

Methods: Pyrolytic graphite (PG) foams were created by randomly dispersing PG powder at various volume fractions (0-5% in 0.5% increments) into a closed-cell polyurethane foam. As calculated using formulae from [1] and [2], at 4.5% PG volume fraction, the composite foam is magnetically isotropic and it matches the magnetic susceptibility of human tissue [1-3]. Off-resonance field maps were acquired to test susceptibility matching with water on 4T Varian and 3T GE scanners. Foam conductivity was measured by RF coil loading Q measurements with a spectrum analyzer (Agilent E5071C). PG foam heating at 4T was measured using an optical probe (Luxtron m3300) during several high-SAR pulse sequences. Fat suppression at 4T was compared with and without a 4.5 cm PG foam shell on an oil–water phantom.

Results: The off-resonance field map (Fig. 1) shows the water and PG foam cylinders are well-matched to the surrounding water, whereas there is a classic ±5ppm dipole pattern outside the air phantom. Figure 2 shows near perfect matching at 4.5% PG volume fraction, and various dipole fields at other volume fractions. Figure 3 shows the electrical conductivities of the PG foams are much lower than that of human tissue as predicted by General Bruggeman theory [4]. Luxtron temperature measurements (Fig. 4) show no discernible effects of heating (< 0.1 °C increase) over 10 minutes of SAR-intensive pulse sequences. Figure 5 shows the PG foam improved the fat-sat suppression significantly. Figure 6 shows PG foam tailored to a Sentinelle breast biopsy-compatible RF coil.

Discussion: PG foams demonstrated excellent tissue susceptibility matching in our experiments. The PG foams produce no MRI signal and, compared to fluid matching agents, are inexpensive, lightweight, and compatible with embedded RF coils. The heating and Q measurements confirm that the foams will be safe and non-conductive, and the foam will add virtually no extra noise to the receiver coil. We believe that PG foams could have many practical applications, such as for improved frequency selective fat suppression for contrast-enhanced breast MRI or spectroscopy [5] and provide robust motion suppression, possibly leading to improved specificity in breast MRI.

References: [1] J. Schenck. Med Phys 23:815-50 (1996). [2] Jelínek et al. Studia Geophysica Et Geodaetica 22:50-62 (1978). [3] Lee et al. Proc. 17th ISMRM, May 2009. [4] P. Chen et al. J Phys D Appl Phys 38:2303-230 (2005). [5] F. Sardanelli et al. Radiol Med 112:1244-1251 (2007).



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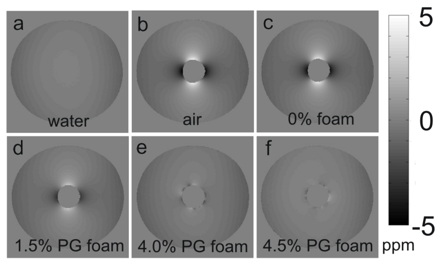

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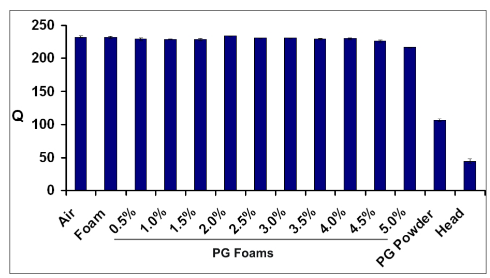

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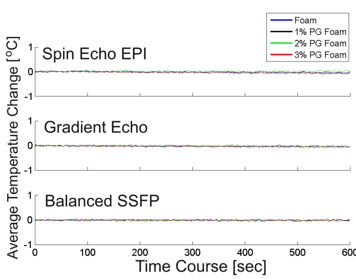

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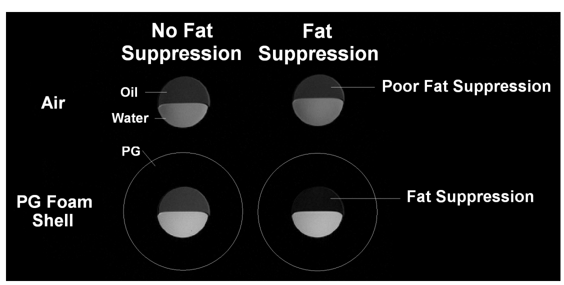

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(6)

Figures: (1) 4T off-resonance field map of air, water, and pyrolytic graphite (PG) foam phantom. PG foam shows reduction in off-resonance effects down to ~1 ppm, relative to air (±5 ppm) at the water interface and thus improved susceptibility matching to water. (2) 3T field maps of air, water, 0%, 1.5%, 4%, and 4.5% PG foams. The dipole field is suppressed outside the 4.5% foam showing near perfect matching. Improved matching outside the 4% foam demonstrates ~10% tolerance in PG volume fraction as well. (3) Q measurements at 4T. Q measurements show the PG foams to be non-conductive, similar to air or regular foam, and thus add no additional noise to the receiver coil. Q for conductive loads of PG powder and human head are also shown for comparison. (4) 10 minute temperature changes at 4T using spin echo EPI (flip = 20°/180°), gradient echo (flip = 80°), and balanced SSFP (flip = 40°) pulse sequences indicates no heating in the foams. |Δtemp| < 0.1 °C. (5) 4T magnitude images of an oil-water phantom with a gradient echo sequence (256x256, FOV 22.4x22.4 cm^2, 3 slices, 3.5 mm thick TR/TE = 500/5 ms) with and without chemical selective fat suppression. Fat suppression in the phantom with the 4.5 cm thick PG foam shell increased 2x from 33% to 66% from the air surrounded phantom case. (6) Preliminary effort to tailor PG foam to a breast specific Sentinelle biopsy-compatible RF coil.