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

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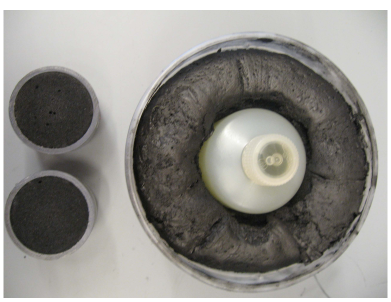
Introduction: Spectrally selective fat suppression methods exploit the 3.5 ppm chemical shift between fat and water to saturate the fat signal in MRI. B_0 field homogeneity must be about 1 ppm for robust fat sat methods. Unfortunately, the field homogeneity near the skin is typically ten times worse than 1 ppm (±5 ppm) due to the air near the skin. Field shimming methods cannot reliably shim out the steep field patterns induced near certain parts of the body (e.g. shoulders or the breast). Here we tested pyrolytic graphite foams that match tissue susceptibility for improved frequency selective fat suppression. We also checked safety heating and conductivities issues for safety. In particular we are targeting robust fat suppression for contrast-enhanced breast MRI.

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

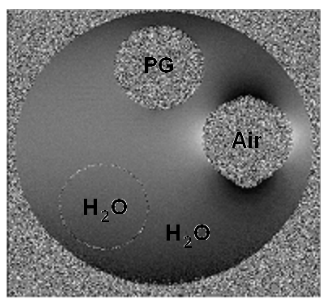
Results: The off-resonance field map of the phantom (Fig. (b)) shows the water and PG foam cylinders are well-matched to the surrounding water, whereas there is a classic ±5ppm dipole pattern outside the air phantom. Figure (c) shows the electrical conductivities of the PG foams are much lower than that of human tissue as predicted by General Bruggeman theory [3]. Luxtron temperature measurements (Fig. (d)) show no discernible effects of heating (< 0.1 °C increase in temperature) over 10 minutes of SAR-intensive pulse sequences. Figure (e) shows the PG foam shell improved the fat-sat suppression significantly.

Discussion: The PG foams demonstrated excellent tissue susceptibility matching in our experiments. The PG foams produce no MRI signal and are inexpensive, lightweight, 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. PG foams could have many practical applications, such as for improved frequency selective fat suppression for contrast-enhanced breast MRI [4].

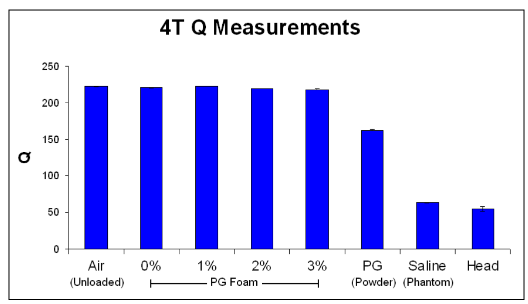
References: [1] J. Schenck. Med Phys 23:815-50 (1996). [2] Shah et al. Proc. 15th ISMRM, May 2007. [3] P. Chen et al. J Phys D Appl Phys 38:2303-230 (2005). [4] F. Sardanelli et al. Radiol Med 112:1244-1251 (2007).



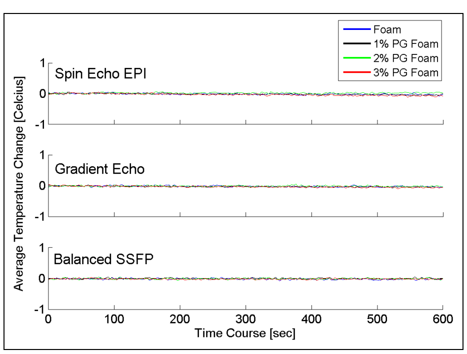
(a)



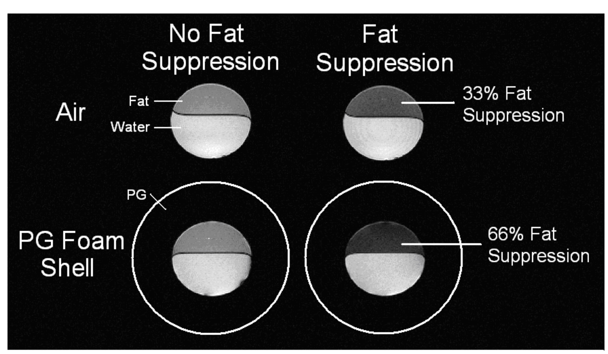
(b)



(c)



(d)



(e)

Figures: (a) Tissue susceptibility matched pyrolytic graphite foams. (b) 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. (c) Q measurements at 4T. Q measurements show the PG foams to be non-conductive, similar to air or regular foams, and thus add no additional noise to the receiver coil. Q for conductive loads of PG powder, saline solution, and human head are also shown for comparison. (d) 10 minute temperature changes using spin echo EPI (flip = 20°/180°), gradient echo (flip = 80°), and balanced SSFP (flip = 40°) pulse sequences indicates no heating in the foams. $|\Delta temp| < 0.1$ °C. (e) 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.