An Improved Pyrolytic Graphite Foam for Tissue Susceptibility Matching in MRI

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Introduction: Field gradients near air-tissue susceptibility interfaces can lead to artifacts including poor fat suppression, image shifts, blurring, or dropouts. External water bags can remove the susceptibility gradient from the imaging volume, but these are heavy and are unsafe with embedded RF coils. Here we improve on a closed-cell pyrolytic graphite foam that matches human tissue susceptibility, is ten times lighter than water, and is compatible with embedded RF coils.

Theory: Pyrolytic graphite (PG) is an anisotropic crystal with –595 ppm susceptibility across plane and –9 ppm through plane [1]. We calculated that a *randomly oriented* distribution of PG powder with volume fraction f in air (or dispersed uniformly in a foam) has bulk susceptibility = $(-298f + 0.36)$ ppm. Moreover, this bulk susceptibility is *isotropic*. Hence, to match human tissue of –9 ppm, we choose $f = 0.031$. The dilution tolerance is not stringent; 10% accuracy guarantees better than 1 ppm susceptibility matching. Magnetic field analysis showed that the PG particle size should be smaller than about 250 microns. Using the General Bruggerman method [2], electrical conductivity of the PG foam was found to be dominated by the low-conductivity foam rather than the high-conductivity PG. Hence the PG foam is less conductive than human tissue, which is critical for maintaining image SNR.

Methods: High purity graphite powder with volume fraction $f = 0.03$ was dispersed into a closed-cell polymer foam (NuSil Technologies). A phantom was created with three air-tight plastic jars oriented perpendicular to the B0 field, and immersed in a right cylinder filled with MnCl2-doped water. One jar was filled with the PG-foam one with air, and one with water. Off-resonance field plots were obtained on a 1.5T GE Excite scanner by taking the phase difference between two 3D GRE images with a ΔTE = 2 ms (TE= 8ms and 10 ms; TR=22ms). PG crystal heating was tested by holding the PG foam in the 1.5 T scanner during several SAR-intense pulse sequences, including RARE, for a duration of 20 minutes.

Results: Figure 1 shows the off-resonance image of the three jars in water. Note the classic dipole field outside the air-filled jar, as expected. The PG foam composite has excellent susceptibility matching, comparable with the water-filled jar. The closed-cell foam is comfortable, only slightly compressible, and is low conductivity. Initial human tests could detect no temperature changes due to RF heating during several SAR-intensive pulse sequences.

Discussion & Conclusion: For this initial experiment, the concentration of PG differed from the targeted concentration. However, the susceptibility matching was still excellent (5-fold reduction in off-resonance). PG-foam pads may be useful for MRI near the foot, hands, chin, breast, neck, shoulder, head, knee, ear plugs, patient pads. Unlike water bags, PG foam is 10x lighter, produces no noise or MRI signal, and is safe and compatible with RF coils. PG foams could significantly improve the robustness of MRI, especially for high field MRI, fMRI, balanced-SSFP, and spectroscopy.

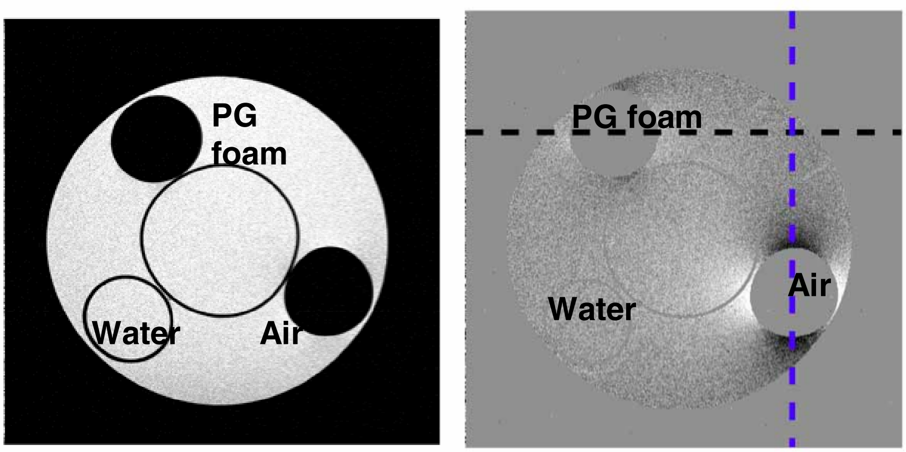

Figure 1: Left shows the magnitude image, and on right we show the off-resonance map (-200 Hz to 200Hz). Note the dipole field outside the air-filled jar, as expected. The PG foam composite has good susceptibility matching, comparable with the water-filled jar (and a 5-fold reduction in off-resonance for this case). The PG foam is 10x lighter than water, safe with RF coils, and produces no noise or MRI signal, unlike matching with water bags.

References:

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