Temperature Mapping with IDEAL Water-Fat Phase Differences

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Introduction Hyperthermia shows promise as both a primary (HIFU-High frequency focused ultrasound) and adjunct therapy (conventional, low level heating with radiation therapy) in such cases as recurrent cancer in the chest wall [1]. Accurate tumor and normal tissue temperature measurement is a key factor for successful treatment. Invasive thermometry provides accurate but spatially limited measurements. Regional temperature mapping via MR methods should increase control of the therapy distribution. Previous work has shown the value of using the temperature sensitivity of the tissue water proton resonant frequency shift (PRFS) [2]. However, tissues with a mix of water and lipids, e.g. breast, confound most standard PRFS approaches since lipids have no chemical shift dependencies with temperature.

Theory The standard IDEAL [3] model for water and fat is shown in Eq.1. If the water frequency changes with temperature, this adds a phase change in the water term. Standard IDEAL post-processing models water as on-resonance, so phase shifts from temperature changes appear in the fat term shown in Eq.2. where $\phi_{\Delta T} = \omega_{\Delta T} TE_2$ and TE_2 is the second of three echo times used for the three-point acquisition. This apparent temperature dependent phase change in fat can be solved for by calculating the voxel water-fat phase angle difference between each time point.

$$S(t_n) = \left(A_w e^{i\phi_w} + A_f e^{i\phi_f} e^{i\omega_{cs} t_n}\right) e^{i\Psi t_n} \quad [1]$$

$$S(t_n) \approx \left(A_w e^{i\phi_w} + A_f e^{i\phi_f} e^{i\omega_{cs} t_n} e^{-i\phi_{\Delta T}}\right) e^{i\Psi' t_n} \quad [2]$$

Methods A water-fat phantom consisting of a safflower oil-in-gelatin dispersion [4] was created in a 5x14 in (diam x length) cylinder. A catheter was inserted along the length of the phantom offset from the center. A Luxtron fluorescent probe measured actual temperature during all image acquisitions. The phantom was actively heated in a mini anular phased array [5] with 4 RF antennas coupled through a water bolus sleeve (see Fig. 1A) at 140 MHz. Gradient echo images (GRE) were taken on a GE 1.5T system. 52 data points were taken over 60 minutes, with 15 min heat OFF, 35 min heat ON (15W x 4 channels), and 10 min heat OFF. Three images were acquired at each time point with TE=[15.1, 16.6, 18.1ms], TR=34ms, FOV=30cm, 128x128 pts, 4 axial slices 10mm thick, BW 32kHz. Complex data was transferred offline and reconstructed using in-house software written in IDL (ITT-VIS, Boulder, CO).

Results Fig. 1 (A,B,C) shows a GRE image and calculated water and fat magnitude images for the first time point. Areas of water only, oil only and mixed water+oil are indicated. A plot of the total temperature change across 60 minutes for the ROI in (A) is shown in (D). The ROI is overlaid on the Luxtron probe location. Calculated values for IDEAL-Temp agree well with Luxtron values and range from -0.4 to +17.3 °C (for 64 MHz, 16.6ms TE, and 0.01 ppm/°C). Temperature maps (E) show a smooth transition of values both spatially and temporally.

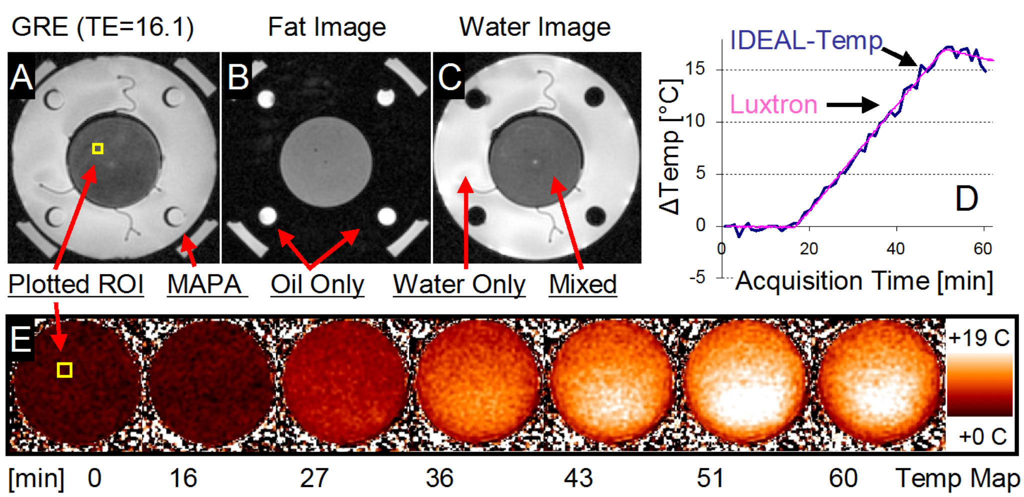

Figure 1. Images and Temperature changes over time for one slice.

Discussion The standard deviation of temperature values while heat was initially off (0-15 min) was ±0.329 °C. Nominal voxel size was 2.4 x 2.4 x 10mm. Because temperature changes were self-referenced by the phase change between the water and fat signals, the effects of B_0 drift over the 60 minute heating period (~35 Hz/hr) did not affect the measurement. This data collection was acquired manually, additional slices could be acquired for equal time if the data acquisition were automated. IDEAL water-fat separation methods that measure temperature dependent phase shifts using fat as an internal phase reference show great promise as a new approach for MR thermometry in fatty tissues such as the breast.

References and Acknowledgements 1. Jones EL, etal, Clin Cancer Res 10, 4287-4293, 2004. 2. Carter DL etal, Int J Rad Onc Biol Phys 40, 815-822, 1998. 3. Reeder S, etal, Magn Res Med 51, 35-45, 2004. 4. Madsen, etal, Ultrasound Med Biol, 32, 867-874, 2006. 5. Zhang Y, etal, IEEE Trans Biomed Eng, 40, 780–787, 1993. Supported by PHS Grant P01 CA04275