PRF Thermometry Using Iterative Decomposition of Water and Fat

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Introduction MR water proton resonance frequency (PRF) thermometry now becomes a promising way in monitoring and controlling local hyperthermia using high intensity focused ultrasound (HIFU) for many clinical applications like tumor ablation. Despite many advantages, the conventional PRF method has yet several problems that may influence the precision of quantitative temperature mapping, like the presence of lipid proton (1), inter-views/ intra-view motion, and frequency drift due to unstable field. It is considered that using separated fat signal is a possible approach to minimize these problems. An iterative algorithm called IDEAL is proposed by Reeder et al. and has primarily been used for water and fat separation (2, 3). Here, we propose to modify the IDEAL method that allows the temperature determination, separation of fat from water to minimize the fat effects, and separation of temperature from the field map to minimize the field drift effects at the same time. The new method is demonstrated in phantom and preliminary results are presented. The feasibility of the new method for MR PRF thermometry is discussed.

Method The algorithm of iterative decomposition of water and fat is modified by introducing a temperature related term $\phi(T)$. Thus, the received MR signal at echo time TE can be modeled as: $S(TE) = (We^{j\phi(T)} + Fe^{j\theta})e^{j2\pi\psi TE}$ [1], W and F are water and fat intensity, respectively. In general they are complex terms due to B_1 inhomogeneity, k-space sampling shift and other scanner related factors. The $\phi(T)$ represents the temperature-dependent phase shift. For GRE, $\phi(T)$ is expected to be:$2\pi TE-\gamma B_0\,\alpha(T- T_{ref})$ [2]. θ denotes the evolution of phase difference of water and fat at echo time TE at reference temperature T_{ref}. For GRE, θ is expected to be : $2\pi\,\Delta f_{f\text{-}w}TE$, where $\Delta f_{f\text{-}w}$ is the chemical shift of fat relative to water. Ψ represents the local B_0 field inhomogeneity. Now Eq. [1] has 6 variables that need to be determined: two complex unknowns (real and imaginary parts of W and F) and two scalar unknowns ($\varphi(T)$ and Ψ). In theory, at least three images are required to determine the six unknown variables since each image contains real and imaginary parts. However, due to the noise and other system factors, four or more images with different TEs are required in our work. To solve the above nonlinear equations, we use the Newton-Raphson iterative algorithm. During the experiment, a phantom was made by mixing boiled whipping cream (fat is 36%) with agar. After cooling, the phantom became solid jelly. It was then placed in a container filled with boiled water and scanned on a Siemens Sonata 1.5T MR scanner using single channel head coil. To verify the temperature measurement by the method, a copper-constantan thermocouple probe (Physitemp Instruments, Inc., New Jersey) connected to a common multi-channel digital temperature reader was used to record the real temperature. For each temperature measurement, four GRE sequences with different TEs (5.6,7.1,8.6,10.1ms, θ=5π/2, 19π/6, 23π/6, 9π/2) were scanned sequentially. Additional imaging parameters were TR/BW/Flip/ FOV/slice thickness/data matrix/averages = 112ms/ ±16.64kHz / 25°/150 x 200 cm/3mm/128 x 128/2.

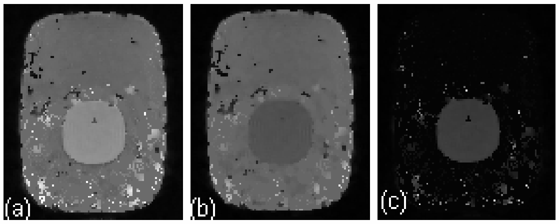

Fig.1: Fat and water separation results. Recombined (a), calculated water (b), calculated fat(c) images.

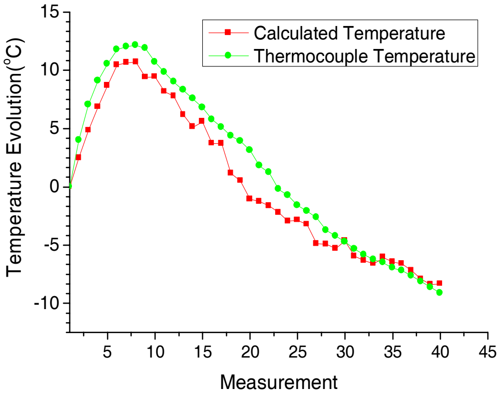

Fig.2: Temperature measured by thermocouple in the phantom and temperature calculated by our new algorithm.

Results Figure 1 shows an image of the phantom acquired with imaging parameters described above and images calculated by our method. The recombined, calculated water and fat images are shown in Figure 1(a), (b) and (c), respectively. Figure 2 shows the temperature evolution curve measured by thermocouple and calculated from our algorithm. The standard deviation of the temperature estimation error is 1.22°C. The temperature obtained by our method is quite consistent with the real temperature measurement by the thermocouple.

Discussion/Conclusion The preliminary results indicate that the new developed method can be expected to map temperature, separate fat from water, and separate temperature information from the field map quite well. Besides, the algorithm can provide fat and water images along with field map estimation simultaneously, which may be an advantage for some applications. From its principle, using the new algorithm for MR thermometry can naturally get rid of the errors in temperature estimation created by the fractions of fat and frequency drift due to unstable field. Now a new pulse sequence is being developed so that all four echoes are acquired in a single TR acquisition to decrease the acquisition time and thus reduce motion artifacts. The performance of our method needs to be optimized so that the difference between the results calculated from our method and those measured from the thermocouple can be minimized.

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