Hybrid Multibaseline and Referenceless PRF-Shift Thermometry Using Both Water and Fat Images

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Introduction Proton resonance frequency (PRF)-shift MR thermometry is a promising tool for guiding thermal therapies in organs such as the breast [1] and prostate, but is complicated by motion and time-varying main field changes. To address motion, a hybrid multibaseline subtraction and referenceless thermometry technique has been proposed [2] which is robust to motion and time-varying main field changes. Since fat does not experience a resonance frequency shift with temperature, it must be suppressed or separated from the water signal prior to temperature estimation. Alternatively, fat can be used as an additional reference for estimating the time-varying main field changes [3-5], which can be difficult to determine using the water signal alone in organs such as the breast and prostate, since these organs are small relative to typical hot spot sizes. In this work we introduce an extension of the hybrid thermometry method that estimates baseline images and time-varying main field change-induced phase shifts from fat and water images simultaneously, which in particular improves the estimation of large hot spots and permits the use of higher-order models for main field change-induced phase shifts.

Theory The method estimates temperature by fitting the following models for the water and fat signals (f^w and f^f, respectively) at voxel j:

$$f_j^w = \left(\sum_{l=1}^{N_l} w_l x_{l,j}^w \right) e^{\imath(\{\boldsymbol{Ac}\}_j + t_j)}$$

$$f_j^f = \left(\sum_{l=1}^{N_l} w_l x_{l,j}^f \right) e^{\imath(\{\boldsymbol{Ac}\}_j + \Delta\phi_f)}$$

where the w_l are the baseline image weights, the $\boldsymbol{x}_l^{w/f}$ are the (complex) water and fat baseline images, $\boldsymbol{A}$ and $\boldsymbol{c}$ are a polynomial basis matrix and coefficient vector, respectively, which model phase shifts due to time-varying main field changes, $\boldsymbol{t}$ is the temperature-induced phase shift, and $\Delta\varphi_f$ is the phase shift of fat relative to water. The method estimates $\boldsymbol{w}$, $\boldsymbol{c}$, and $\boldsymbol{t}$ while encouraging $\boldsymbol{t}$ to be sparse, reflecting prior knowledge that heat is applied focally. The main advantage of fitting jointly to both fat and water images is that the fat image does not contain the temperature-induced phase shift $\boldsymbol{t}$, improving the separation of $\boldsymbol{t}$ from the main field change-induced phase shift $\boldsymbol{Ac}$.

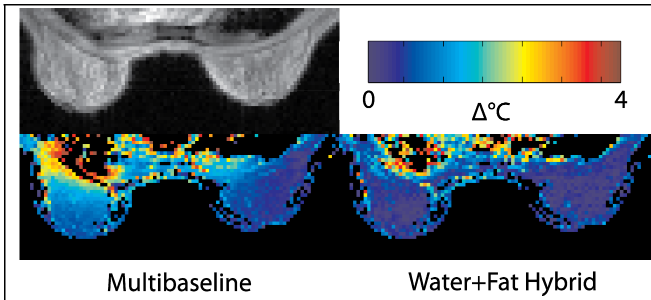

Figure 1: Breast Results. (Top) Breast image from a single echo. (Bottom) Average temperature errors across 5 images for multibaseline and water+fat hybrid thermometry, with 4 library images. The multibaseline errors are largest near the chest wall, where heart motion and respiration induce large main field changes that are not compensated by that method.

Methods We compared the water+fat hybrid method with multibaseline thermometry in the breast without heating and with the standard (water-only) hybrid method in the canine prostate during HIFU ablation. Five breast images were acquired on a GE 3T scanner (GEHC, Waukesha, WI) with an 8-channel breast array using an IDEAL sequence [5] (TE = {10.9, 12.5, 14.1} ms) in two breath-holds. Prostate images were acquired at 0.5T GE scanner using a multi-echo sequence (TE = {14.3, 21.4, 28.6} ms). In the breast dataset hybrid thermometry was performed on each of the 5 images with a 6th order polynomial matrix $\boldsymbol{A}$ and with a baseline library formed in a leave-one-out fashion. In the prostate dataset the hybrid methods were run on a single image with 2nd and 10th order background polynomials and a baseline library comprising a single image acquired prior to heating.

Results Figure 1 shows average temperature estimation errors in the breast images. The water+fat hybrid method achieves substantially lower errors than the multibaseline method, particularly near the chest wall where the main field changes the most. Figure 2 shows the prostate results, which illustrate that the water+fat hybrid method provides accurate temperature estimates regardless of main field phase shift model complexity. Conversely, a larger hot spot can be accurately estimated for a fixed main field phase shift model complexity.

Conclusion We have introduced an extension to the hybrid multibaseline subtraction and referenceless thermometry method that enables robust hybrid thermometry in organs surrounded by fat such as the prostate, and in organs with inhomogeneous fat and water distribution such as the breast. The method uses fat as a reference to improve estimates of the main field phase shift component of the hybrid image model. In practice the improvement in performance will be largest when the size of the organ is small relative to the hot spot size, or when a complex model is required to capture main field change-induced phase shifts, so that the fat image plays a larger role in determining main field change-induced phase shifts.

References [1] D Gianfelice et al. Radiology 227:849-855, 2003. [2] W A Grissom et al. Med Phys 37:5014-26, 2010. [3] K Kuroda et al. MRM 38:845-851, 1997. [4] L Hofstetter et al. ISMRM 2010, p. 245. [5] V Rieke et al. IEEE TMI 26:813-821, 2007.

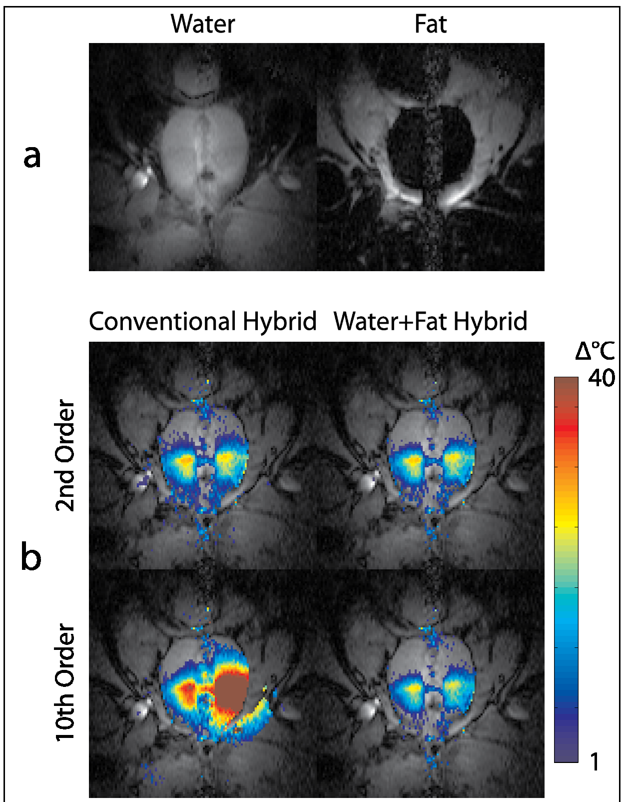

Figure 2: Prostate Results. (a) Water and fat images in the canine prostate. (b) While both methods estimate the same hot spots with 2nd order main field phase shift models, due to the small size of the prostate relative to the hot spot the conventional method fails when a more complex (10th order) model is used, while the water+fat method continues to estimate temperature accurately since it estimates the model parameters also from the fat surrounding the organ.