Fat-Referenced MR Thermometry during Canine Prostate Ablation

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Introduction: MR thermometry is increasingly required to monitor and guide focused ultrasound (FUS) ablation procedures, such as in the prostate [1,2]. During the FUS ablation, temperature mapping is used to ensure adequate thermal dose delivery to the treatment region and to avoid unnecessary heating of the rectum and neurovascular bundle [2]. However, the conventional proton resonance frequency shift (PRFS) thermometry technique [3] is sensitive to time-varying $B_0$ field disturbances. It has been shown that fat signal can be used to measure and correct for these field disturbances [4-6]. In this work we test a 3-echo fat-referenced thermometry technique [7,8] during a canine prostate ablation procedure. For comparison purposes, conventional and corrected PRFS measurements are also computed.

Methods: This study was done in compliance with Animal Studies Ethical Committee approved protocols. Canine prostate ablation was performed using a 1000-element transrectal FUS transducer (InSightec, Tirat Carmel, Israel). MR imaging was performed on a 1.5T GE scanner (GE Healthcare, Waukesha, WI) with an 8-channel torso array coil. A multi-echo multi-slice spoiled-gradient-recalled acquisition (SPGR) with flyback gradients was used for each thermometry measurement. Imaging over 3 axial slices was achieved in under 7 seconds using the following imaging parameters: TE {10.3ms, 12.7ms, 15.1ms}, TR = 52ms, flip = 20°, FOV = 36cm, matrix 128×128, 4mm slice, bandwidth 100 kHz. After initial positioning of the FUS transducer, the balloon surrounding the transducer was filled with cold (14°C) degassed water to provide rectal wall cooling during the procedure. After anatomy temperature equilibrated, a baseline thermometry acquisition was acquired. Ablation of the left prostate lobe was achieved with six separate sonication sets. Following completion of the final set, (83 minutes after the baseline acquisition) a second fat-referenced thermometry acquisition was performed.

Fat phase ($\phi_f$) and water phase ($\phi_w$) images were computed for each 3-echo measurement using the phase-based separation method described in Ref. [8]. The difference between measurement and baseline fat phase images ($\Delta \phi_f$) was interpolated using a 2D second-order spatially-varying polynomial to generate a phase disturbance correction map ($\Delta \phi_h$). The fat referenced temperature change ($\Delta T$) is computed according to:

$$\Delta T = \frac{\Delta \phi_w - \Delta \phi_h}{\gamma a B_0 TE}$$

where TE = 12.7ms was used in the equation denominator. The conventional PRFS thermometry measurement was computed using a subset of the multi-echo SPGR dataset (images acquired with TE = 12.7ms). A drift-corrected PRFS measurement was also computed by measuring the DC component of the $B_0$ field drift in an unheated region of muscle tissue (green ROI in Fig 1b) and subtracting this measured value from the conventional PRFS temperature map.

Results: The experiment setup and transducer positioning are shown in Fig 1a. Reconstructed water and fat magnitude images are shown in Fig 1c and Fig 1d, respectively. The conventional, drift-corrected, and fat-referenced temperature maps are depicted in Fig 2. Phase drift is readily apparent in the conventional PRFS measurement as denoted by the large (~20°C) negative temperature change values in the unheated muscle regions. A thermocouple in the mouth confirmed that a core body temperature of 35°C was maintained for the experiment duration. The negative temperature values encountered in the conventional PRFs were not seen in the fat-referenced approach. The fat-referenced and drift-corrected PRFS techniques corrected for this time-varying $B_0$ field disturbance.

Conclusion: We have demonstrated using a 3-echo fat-referenced thermometry technique during a canine prostate ablation procedure to correct for measurement errors caused by time-varying $B_0$ field perturbations. Although these perturbations were also corrected in the drift-corrected PRFS measurement, this method required that the reference region temperature was constant for the experiment duration. To ensure this, a region far from the treatment zone was selected. The fat-referenced technique is not limited by this constraint, and all regions of fat (even in the heated area) were used to provide a more complete spatial sampling of the time-varying $B_0$ field perturbations.