Real-time hybrid MR thermometry of human ventricular myocardium with and without blood suppression

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Introduction: In recent years there has been increased interest to perform cardiac interventions, such as catheter ablation under MR-guidance. Directly monitoring the temperature rise during these procedures could potentially be helpful to verify successful ablation and predict treatment outcome. In this study, we investigate the feasibility of monitoring temperature changes in the left ventricular myocardium in real-time using spiral imaging at 3T with varying imaging parameters with [1] and without blood suppression. Temperature images based on the proton resonance frequency (PRF) shift are reconstructed using a hybrid method [2] that combines multi-baseline subtraction and referenceless thermometry.

Materials and Methods: Short-axis free-breathing ungated cardiac images were acquired in three volunteers (no heat applied) in real-time using spiral gradient echo acquisitions with 4-5 interleaves on a 3T scanner. To test the influence of imaging parameters on the uncertainty in the temperature maps, echo times of 3 ms, 5 ms, and 7 ms, and slice thicknesses of 5 mm and 10 mm were tested (TR = 23-27 ms). We also compared cardiac images acquired with and without blood suppression using inflow saturation (IS) by placing one 8 cm saturation slab at the base of the heart in one volunteer. All images were acquired with a single 5-inch surface coil.

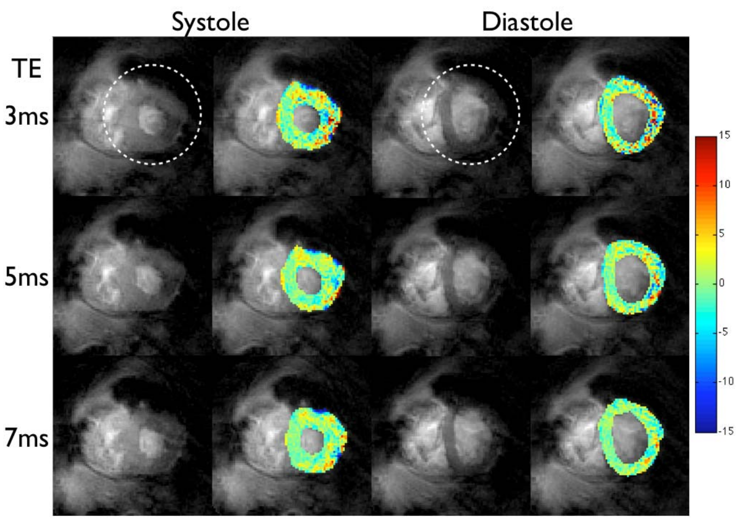

Figure 1. Magnitude images and temperature overlay onto the left ventricular myocardium showing the temperature uncertainty for three different echo times during systole and diastole. The dashed circle shows the circular regions for the hybrid temperature estimation.

Hybrid temperature image reconstruction was performed off-line in Matlab. The hybrid imaging model assumes that three sources contribute to image phase during thermal treatment: Background anatomical phase (estimated by the multi-baseline portion), spatially smooth phase deviations (estimated by the referenceless portion), and focal, heat-induced phase shifts (residual).

For the referenceless portion of the processing, sixth-order background polynomials were used and for the multi-baseline portion baseline libraries were comprised of 150 images (sliding window reconstruction) acquired during free breathing, representing approximately three cardiac cycles. Temperature reconstruction was performed over circular regions of interest (ROI) containing the entire left ventricle (shown in Fig. 1). Temperature uncertainty (σ_T) was measured in ROIs manually selected in the septum and the free ventricular wall in images during systole and diastole.

Results: The lowest temperature uncertainty was always measured in the septum during systole (σ_T=1.0ºC), followed by septum during diastole (σ_T=1.3ºC), and then free wall during systole (σ_T=2.4ºC). The temperature uncertainty was always highest in the free wall during diastole (σ_T=3.7ºC; all values for TE = 7ms and 10 mm slice). Increasing the slice thickness from 5 mm to 10 mm decreases σ_T in all cases.

The results show that increasing the echo time from 3 ms to 7 ms decreases the temperature uncertainty. However, in the third volunteer σ_T in the free ventricular wall actually increased at 7 ms compared to 5 ms during diastole. In this case, T2* decay due to poor shimming caused very low signal in the free wall.

Using a single 8 cm saturation slab at the base of the heart did not suppress the blood in all cardiac phases. While complete blood suppression was achieved during diastole, blood signal was still seen during systole. There was no noticeable difference in temperature measurements inside the myocardium with and without blood suppression.

Discussion: The results show that temperature monitoring in the left ventricular myocardium is feasible with the hybrid method in real-time. Echo times have to be chosen carefully: a longer TE allows for longer phase accrual, but increases T2* decay especially in the free wall near the lungs. This observation is in agreement with the optimum echo time for lowest σ_T, which is at TE = T2*, although actual T2* values were not measured in this study. Therefore, good shimming is necessary to minimize T2* signal loss.

Blood suppression did not appear to effect temperature measurements in the myocardium. However, blood suppression may help enable automatic selection of the myocardium for the temperature overlay (which was manually selected for Fig. 1). Extending the method to multi-coil reconstruction [1] could be helpful if reconstruction times can be decreased to allow for real-time temperature reconstruction.

Conclusion: Temperature measurements in the left ventricular myocardium in real-time with a hybrid referenceless and multi-baseline method can achieve low temperature uncertainties that make in vivo thermal ablation monitoring feasible.

References
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[2] W. Grissom et al. Hybrid referenceless and multi-baseline subtraction MR thermometry for monitoring thermal therapies in moving organs. Medical Physics, 37:5014-26, 2010.