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Hybrid referenceless and multi-baseline subtraction thermometry for monitoring thermal therapies in the heart

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Introduction

Proton resonance frequency (PRF)-shift MR thermometry is a promising technique for guiding ablative treatment of heart arrhythmias, but is complicated by heart motion and respiration. To address motion, multi-baseline subtraction techniques have been proposed [1,2] that use a library of pre-treatment baseline images covering the cardiac and respiratory cycle.

However, main field shifts due to lung and diaphragm motion can still cause large inaccuracies in multi-baseline subtraction. In contrast, referenceless thermometry methods [3-5] based on polynomial phase regression are immune to motion and susceptibility shifts. While referenceless methods can be accurate in localized regions of the heart, in general the background phase in the myocardial wall requires large polynomial orders to fit, leading to increased danger that the hot spot itself will be fit by the polynomial and thermal dose will be underestimated.

We present a new, hybrid method for cardiac thermometry that combines the strengths of referenceless and multi-baseline thermometry. The method requires no gating, navigator acquisitions, or susceptibility modeling. We demonstrate that the method estimates temperature with much lower error in the left ventricular myocardium of a volunteer, compared to multi-baseline subtraction and referenceless methods.

Methods

The new algorithm is an extension of the regularized referenceless thermometry method in [5], in which a temperature change map is jointly estimated with a polynomial background phase map. Here we also jointly estimate a set of weights that synthesize a baseline image as a linear combination of images from the baseline library. Sixth-order background polynomials were used for both the referenceless and hybrid methods, and the baseline library comprised 1.725 seconds of free-breathing (75 images). We compared our algorithm with the referenceless thermometry method in [5] and with multibaseline subtraction performed using our method without polynomial phase regression. Short-axis free-breathing images were acquired in a volunteer in real-time [6], using spiral acquisitions with four interleaves (TR = 23 ms, TE = 5 ms) on a GE 3 T Signa HDx scanner (GE Healthcare, Waukesha, WI).

Results

Figure 1 shows temperature estimation results from images in a diastolic phase 4.025 seconds after library acquisition, and in a systolic phase 4.784 seconds after library acquisition. A mask containing the septum and left ventricular myocardium was derived, and the temperature is displayed in that region. Nominally, each method estimates zero temperature in this region, however, Fig. 1 shows that the referenceless method is unable to fully regress out the background phase, leaving large residual temperature errors (std = 18.2°C diastole, std = 20.3°C

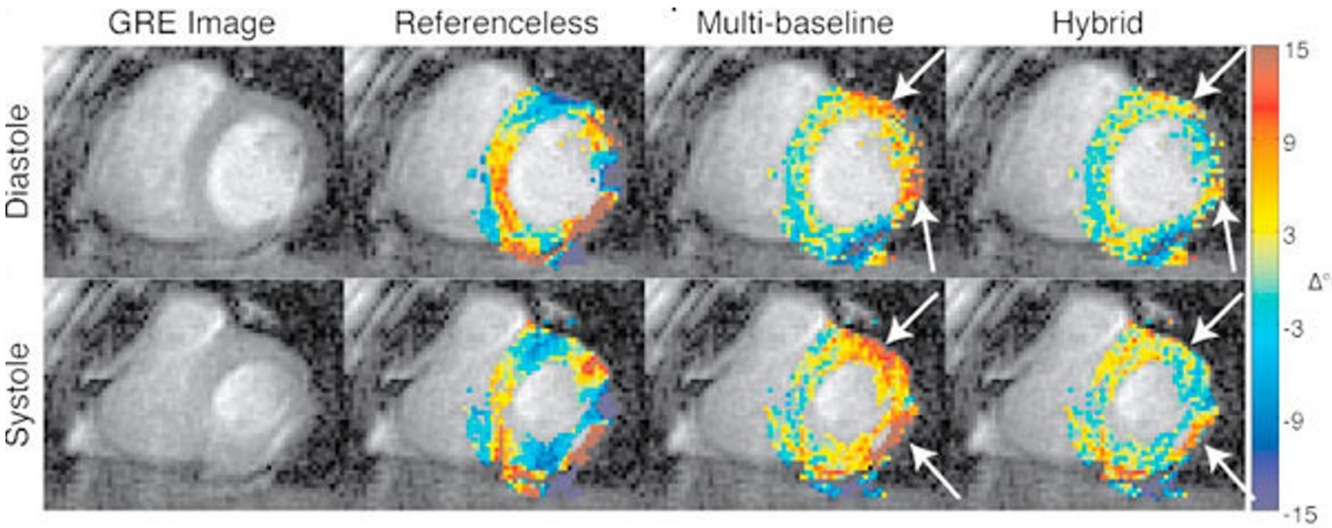

Figure 1
Experimental results during free-breathing. The new hybrid method estimates significantly smaller temperature shifts in the ventricular myocardium than the other two methods.

systole). The multi-baseline method achieves significantly lower errors, however, large errors remain near the lung and diaphragm (white arrows, std = 5.6°C diastole, std = 7.3°C systole). In contrast, the hybrid method achieves lower error throughout the myocardium (std = 4.2°C, std = 5.7°C systole).

Conclusion

We have introduced a new hybrid method for PRF-shift thermometry in the heart, and demonstrated its ability to estimate temperature with higher accuracy than conventional methods. As in multi-baseline subtraction methods, the new method is capable of removing highly-structured background image phase in the presence of motion. As in referenceless thermometry, the method is robust to susceptibility-induced main field shifts due to lung and diaphragm motion.