PRF based MR-Thermometry on Abdominal Organs: A pragmatic comparison of referenceless vs multi-baseline

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Introduction

Reliable temperature and thermal-dose measurements using PRF based MR-thermometry for MR-guided ablation therapy on abdominal organs are complicated by the fact that the target moves through an inhomogeneous and time-variant magnetic field. Two correction approaches emerged recently as the most promising candidates to allow continuous real-time MR-thermometry under free-breathing conditions [1]: The multi-baseline correction method [2,3] which relies on a pre-recorded correction table allowing to correct for periodic phase changes, and the referenceless method [4] which depends on a background phase estimation in the target area based on the assumption of a smooth background phase across the organ. The presented study combines both methods with real-time in-plane motion correction [5] to permit thermal-dose calculations and compares the practical aspects of both methods in a typical application scenario of an ex-vivo RF-ablation and an in-vivo high-intensity focused ultrasound (HIFU) ablation on a porcine kidney.

Materials and Methods

Rapid gradient recalled EPI imaging using a 1.5T Philips Achieva (Philips Healthcare, Best, The Netherlands) is performed during RF-ablation (bi-polar, 8 Watts, 85 seconds, MRI: 3000 images, single-slice, TR=18 ms, TE=8.8 ms, 14 img/s, 2×2×6 mm^3, matrix 128×52, 11 lines per excitation, BW=1.7 kHz) and HIFU (60 seconds, acoustic power: 100 W, MRI: 1500 coronal images, single-slice, single-shot EPI, TR=100 ms, TE=41 ms, 2.5×2.5×6 mm^3, matrix 128×84, BW=2.1 kHz) with a sufficiently high temporal resolution to resolve the respiratory cycle.

The RF-experiments were performed ex-vivo on a motorized platform simulating respiratory motion and the HIFU ablation experiments in-vivo on a porcine kidney, respectively. The incoming images are co-registered in real-time on a voxel-by-voxel basis to a common reference position using first a principal displacement component (PDC) estimation to precondition a subsequent optical-flow based displacement estimation [5] before they are subjected to either a multi-baseline phase correction or alternatively to a referenceless phase correction:

Multi-baseline MR-Thermometry: N magnitude images together with the co-registered phase images and the corresponding displacement vector fields are collected in a pre-recorded look-up table (N=100). The coefficients of a system of N equations expressing the unwrapped registered phase of each individual voxel as a linear combination of the six PDCs are solved using a Singular Value Decomposition. This model is used in the interventional phase to re-synthesize a corresponding background phase image from the displacement vector field of each newly arriving image as explained in detail by [5].

Referenceless MR-Thermometry: A background phase estimate is obtained by fitting a polynomial function to the measured phase obtained from a region of interest (ROI) outside the treatment area, which is assumed to remain at body temperature. To eliminate potential phase wraps, the phase in the ROI is spatially unwrapped before polynomial fitting [4]. The appropriate size and location of the ROI as well as the optimal polynomial order for the phase fit are determined before heating. In the presented experiments a polynomial of 5th order adapted by a signal-magnitude weighted least-square fit was found sufficient to represent the phase function.

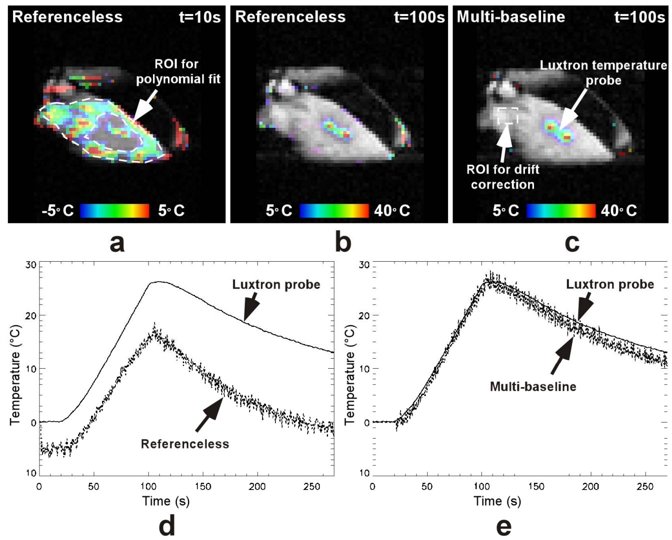

Figure 1. The temperature maps (a,b,c) and the temperature evolution at the position of the Luxtron probe (d,e) for RF-heating reveal the typical problems of both methods: Referenceless (a,b,d) has difficulties correcting small-scale B_0 variations (a) which lead to apparent temperature offsets between MR-thermometry (d, dashed) and temperature probe (d, solid), while multi-baseline requires a lengthy preparation phase (0-20 s) and an additional drift correction.

Results and Discussion

RF-ablation: Figure 1 (c,e) shows the temperature map and evolution of the RF-ablation obtained with the multi-baseline approach compared to the reference temperature. Although both temperature curves match closely, note the difference towards the end due to an insufficient B_0 drift correction (ROI in fig. 1c). The referenceless method shows temperature offsets (d), since the background phase in the vicinity of the RF-electrodes is not correctly represented by the fitted background phase. Furthermore, despite a careful distance of the ROI boundaries from the ablation zone, heat diffusion biased the background phase estimation during the second half of the experiment.

HIFU-ablation: Both methods lead to a comparable temperature evolution shown in figure 2. The precision of MR-thermometry (obtained in a ROI in the vicinity of the ablation area) was evaluated to 0.91 °C ± 0.33 (min=0.53, max=2.56) for multi-baseline and 1.38 °C ± 1.83 (min=0.4, max=13) for referenceless. However, the choice of the fitting ROI for the referenceless approach turned out to have a large influence on the outcome and required several attempts until the optimal placement was found.

Conclusions

Both approaches showed a comparable performance in the *non-invasive* ablation experiment and allowed to follow the temperature and the thermal dose in real-time. While having a comparable precision, the accuracy of referenceless method was found to be limited by variations due to the choice of the fitting ROI and its inability to cope with local B_0 variations at organ boundaries. On the other hand, the multi-baseline approach was limited by its inability to cope with spontaneous motion and its required additional preparation time, the later in particular when paired with low frame-rate imaging. While the multi-baseline method was found fully compatible with *mini-invasive* ablation modalities, the referenceless method would require additional corrections to lead to comparable results.

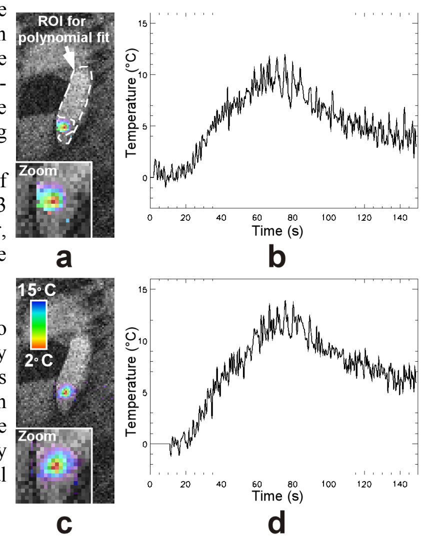

Figure 2. Temperature maps of the in-vivo HIFU ablation of a porcine kidney at peak temperature obtained with referenceless (a) and multi-baseline (c) as well as the corresponding temperature evolution (b,d) of the target region.

References

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