Reference-less PRFS MR thermometry of the whole liver based on near-harmonic calculation: Clinical evaluation from LITT ablation data

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Introduction. Proton Resonance Frequency Shift (PRFS) thermometry is a commonly used technique for non-invasive monitoring of MR-guided thermo-therapies. However, the standard time-referenced PRFS method is highly sensitive to tissue motion and to external perturbations of the magnetic field. Two methods have been described for PRFS MR thermometry in moving organs: multi-baseline approaches [1,2] and reference-less calculations [3,4,5]. Reference-less thermometry was first published by Rieke et al [1], using L2-weighted polynomial interpolation from a rectangular and thick unheated border towards the inner ROI. Initial user-interaction is thus necessary, while placing a convenient ROI may be challenging for real-time interventions on patients. Grissom et al [2] implemented a L1-weighted variant of the polynomial interpolation in order to relax the border constraints, still requiring a small sized area to be heated moderately. The purpose of the current study was to post-process liver LITT patient data with a novel implementation of near-harmonic reference-less PRFS thermometry using a thin and arbitrarily formed border, in particular including nearly the whole liver in the ROI. The background phase inside the domain was calculated by solving a 2D Dirichelet problem using the formalism of harmonic functions, adapted from the original description by Salomir et al [5] to take into account the current configuration.

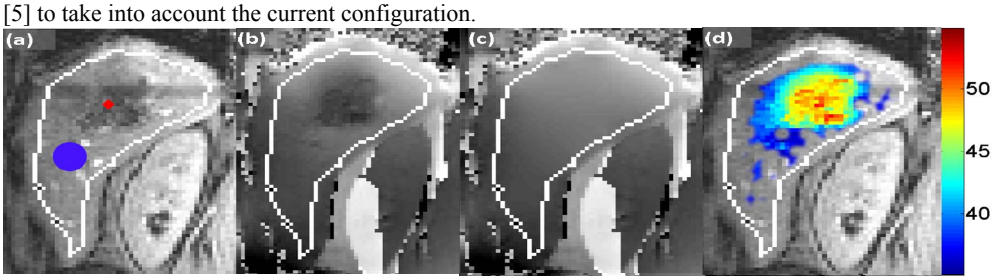

Figure 1: *White voxels define the closed border.*
a). *GRE magnitude image (blue ≡ non-heated ROI; red ≡ heated voxel selected for Figure 2);*
b). *GRE native phase map*
c). *Reconstructed background phase;*
d). *Calculated temperature T>37°C overlaid on magnitude image*

Material and Methods. Six interventions were performed on a 1.5T Avanto MR scanner (Siemens Healthcare, Erlangen, Germany) using Laser Induced Thermal Therapy (LITT) with a Neodym YAG-Laser (Neodym doped Yttrium-Aluminium-Granat-Laser, Medilas fibertom 5100, Dornier, Wessling, Germany) operating at a wavelength of 1064nm and a maximum power of 100W with 1 to 3 applicators. For the interventions, a microcatheter system, with an outer diameter of 1.8mm (5.5F) (Anacath®, Berlin, Germany), was placed under MR guidance. After insertion, the titanium needle was replaced by a laser light guide and thermotherapy was initiated. The study protocol was approved by the local ethics committee and written informed consent was given by all patients. Patients received local anaesthesia (20ml of 1% prilocaine subcutaneously) prior to the intervention. Prior to the procedure all patients also received a mild iv anxiolytic (Haloperidol (10mg haloperidol; 100mg pethinide); TEVA Generics GmbH, Radebeul, Germany). Temperature monitoring was performed under free breathing simultaneously to intervention using a multi slice GRE sequence (TR/TE=950ms/12ms; FA=35°; BW=250Hz/Px; voxel=2.4x2.4x6mm; fat suppression; respiratory triggering; 3 transversal and 1 sagittal slices). The temperature elevation in liver was calculated using the standard time-referenced method and also using the reference-less post processing method with a thin border, proximal to the liver margins (Figure 1). The closed border circumscribed nearly the whole section of the liver visible in the actual slice. The phase on the border must be smooth, free from artefacts and unheated. The results from the two methods were compared over the series of patients. The precision of the temperature calculation for each method was assessed using baseline measurements in non-heated ROIs, see Figure 1.a.

ID #	Tumor size (cm) axial	Tumor size (cm) sagittal	Necrosis size (cm) axial	Necrosis size (cm) sagittal	Liver segment	Nb. of applicators	Laser energy (kJ)	Tumor histology
1	3.8x3.3	3.5x2.7	4.3x4.3	4.1x4.0	8	3	48.1	GC
2	2.2x2.1	2.5x2.2	3.3x3.1	3.1x2.9	4	2	32	RC
3	5.0x2.7	4.9x3.3	4.9x4.2	4.8x4.4	8	3	37	GC
4	2.0x1.9	2.2x2.1	4.0x3.5	4.1x3.2	8	2	32.7	CM
5	5.0x3.8	4.8x3.1	4.8x3.1	5.3x3.1	2	3	44	RC
6	5.2x4.8	4.8x3.7	5.0x4.0	5.0x4.1	4	2	27.5	BC

GC=gastric carcinoma, RC=rectum carcinoma, CM=colorectal metastases, BC=breast carcinoma

Results and Discussion. Within the unheated voxels (i.e. baseline calculation; Figure 2.b.), the standard reference post processing method showed an average precision of ±4°C, while the reference-less method greatly improved this precision to ±0.5°C. An example of the temperature vs. time plots in one heated voxel (Figure 1(a), red mark) during the intervention is shown in Figure 2.a. The temperature values are plotted over time for both the standard reference method and the reference-less method. The absolute offset of the standard temperature measurement in the heated regions compared to the more robust reference-less method was 5.6°C averaged over the 6 patients. The main advantages of the reference-less PRFS method are: robustness against interscan motion and per-operatory flexibility due to the absence of a reference image. By using the current reference-less PRFS method, the ROI for temperature monitoring can be repositioned/resized and the slice orientation/position can be changed during the intervention. As long as the border of the domain is unheated and comprised inside the liver, the actual implementation does not demand any conditions regarding its size or shape.

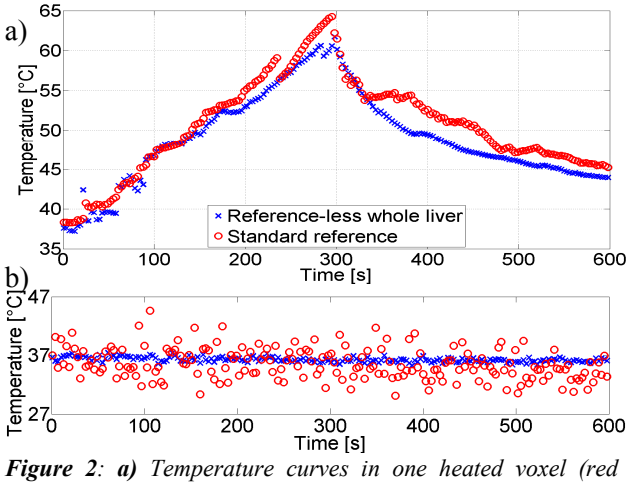

Figure 2*: **a)** Temperature curves in one heated voxel (red marker Fig.1.a), filtered with a multi-exponential pixel-wise model [6] (updated on-the-fly at each sampling point) applied on standard referenced PRFS and, respectively, reference-less MRT calculation data; **b)** Baseline stability (unheated voxel)*

Conclusion. The reference-less PRFS method using a thin border proximal to the liver margins estimates the temperature elevation with significantly better precision than the standard reference method. In addition to known advantages over interscan motion and external perturbation of the magnetic field, this implementation offers higher per-operatory flexibility for MR thermometry and is compatible with a no-user-interaction scenario for reference-less temperature monitoring over the entire liver if automatic organ segmentation could be provided.

References. [1] de Senneville. Magn Reson Med 2007;57:319–330. [2] Vigen Magn Reson Med 2003;50:1003-1010. [3] Rieke Magn Reson Med 2004;51:1223–1231. [4] Grissom Magn Reson Med 2010;64:1068-1077. [5] Salomir ISMRM 2010 Stockholm; #247. [6] Kickhefel ESMRMB 2009 Valencia; #514