Simultaneous T2 mapping in Near-Field Subcutaneous Fat Layer and PRFS Temperature Mapping in the Target Region using Fast Interleaved Sequences to Monitor MR-HIFU Sonication

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Purpose – MR guided high-intensity focused ultrasound (MR-HIFU) is establishing as a new treatment option for various diseases that elegantly combines two non-invasive technologies. Treatment options include HIFU ablation, adjuvant HIFU hyperthermia and HIFU-based local drug delivery. Over the course of a treatment session, near-field ultrasound heating of the skin and heat accumulation in the subcutaneous fat layer may become problematic due to the low thermal conductivity of fat. Currently, temperature mapping based on the proton resonance frequency shift (PRFS) is applied during clinical MR-HIFU treatment. However, reliable PRFS temperature maps can only be acquired in non-adipose tissue, while e.g. T2-mapping based temperature assessment may be used for adipose tissue[1,2]. Simultaneous temperature monitoring would be desirable in separate FOVs, like the adipose far field and non-adipose tumor regions. We propose to use an acquisition technology, which quickly interleaves a PRFS (gradient-echo) and a T2 mapping (dual spin-echo) sequence on the level of individual repetitions with microsecond latency. Feasibility was demonstrated in a model setup using ablation conditions on a clinical MR-HIFU system.

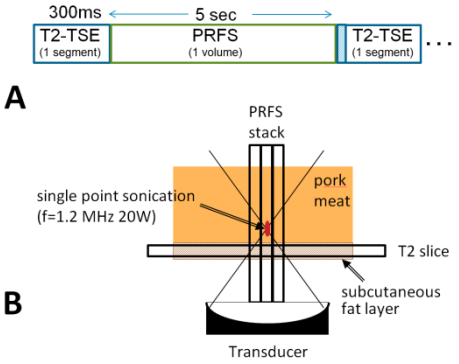

Figure 1: Interleaved sequence timing diagram (A) and experimental setup (B) as applied in simultaneous PRFS temperature mapping and T2-mapping for temperature control in a subcutaneous fat layer.

Methods – A time-interleaved scan protocol (Fig.1 A) was developed containing a PRFS sequence (TR/TE=41/19.5 ms; flip angle = 19.5°; FOV=250×250 mm; resolution = 1.42×1.42 mm^2; slice thickness = 4 mm; EPI factor = 7; 3 slices; NSA = 2; fat suppression; dynamic acquisition time 4 s) and a dual-echo single slice fast spin-echo (TSE) sequence for T2 mapping[2] (TR/TE$_1$/TE$_2$= 581/40/180 ms; FOV=250×250 mm; resolution = 1.42×1.42 mm^2; slice thickness = 5 mm; TSE factor = 40 ; water suppression; temporal resolution = 1.7 min). Real-time switching (latency ≤10 µs) between PRFS (3 slices per interleave) and dual-echo FSE acquisitions (one k-space segment for both echoes per interleave) is performed by defining parallel threads with individually stored runtime variables in the modified MR spectrometer software[3]. Phantom (TO5, Diagnostic Sonar, United Kingdom) and *ex vivo* (pork steak with 1 cm thick subcutaneous fat layer) experiments (Fig.1B) were performed on a 3.0T MR-HIFU system (Sonalleve, Philips Healthcare, Finland) to evaluate potential interferences due to none equilibrium magnetization and accuracy of PRFS and T2 mapping in the interleaved mode during ablation. For the *ex vivo* experiment, a time delay (200ms) was optionally inserted before the T2-mapping segment. The MatMRI and MatHIFU toolboxes[4] were used to retrieve the PRFS images and T2 maps during the ablation of pork meat (single spot; 2×2×7 mm^3; 20 W acoustic power; frequency 1.2 MHz).

Results and Discussion – A linear correlation (R^2=0.997) was found between the calibrated T2 values of the TO5 phantom and the values measured with the interleaved dual-echo TSE, demonstrating no apparent influence of the interleaved PRFS packages on the T2 quantification for the phantom case. *Ex vivo* T2 mapping within the subcutaneous fat layer during and after sonication could be performed with a temporal resolution of 1.5 min over a total period of 24 minutes. Figure 2 shows a snapshot 3D view of the pork meat overlaid with the PRFS temperature map oriented along the HIFU transducer beam axis and the T2 map. The T2 maps acquired during sonication (Fig. 3 A/B/C) and 17min post sonication (Fig. 3D) show the T2 changes over time in great detail. Heat accumulation in a ring shape region in the far field during sonication as well as diffusive spread of the heat and slow temperature decay during the cooling phase was observed. The temporal resolution of interleaved T2 mapping is substantially lower than the temporal resolution of PRFS temperature mapping, but would still be well suited to control the slow heat accumulation in adipose tissue. While PRFS image quality was not found to be compromised by the interleaved scan operation, a delay before the T2-mapping segment (200 ms) improved the T2 image quality in the *ex vivo* pork sonication experiment (but not in the phantom case), which is subject of further investigation.

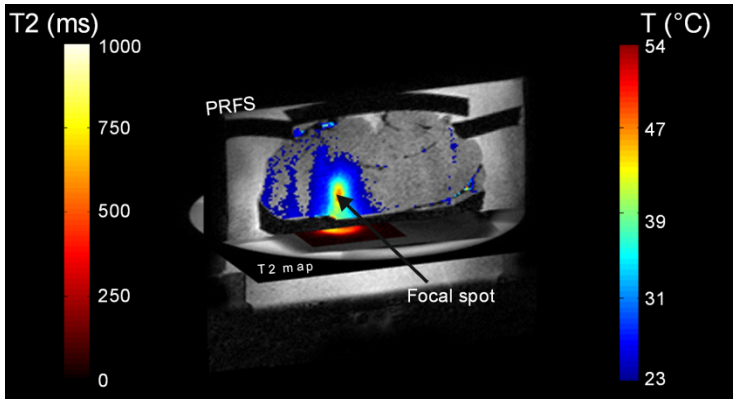

Figure 2: 3D view of the imaging geometry applied in the pork phantom during a single point sonication (20W, 1.2 MHz, 3.5 min). The HIFU transducer is positioned below the phantom and transmits vertically upwards. The PRFS image is overlaid with the temperature map along the beam axis of the HIFU transducer and the dual-echo TSE image plane in the fat layer is overlaid with the T2 map perpendicular to the HIFU transducer beam axis.

Conclusion – Interleaved sequences can provide simultaneous temperature information in the near-field and the target region using a fast field echo sequence in adipose tissue and gradient echo sequence in none-adipose tissue, respectively, with different orientation and/or FOV during a MR-HIFU sonication. With only 6% of the scan time spent for T2-mapping, the PRFS-based real-time temperature is not affected significantly, while the obtained temporal resolution of the T2-mapping should be suitable for the application in simultaneous fat temperature control.

References – 1. Heijman et al., Proc. FUSF Symposium 2012, P-132-EA **2**. Baron et al., MRM 20 (2013) **3**. Gdaniec N et al., Proc. ISMRM 21:3714(2013) **4.** Zaporzan et al., Journal of Therapeutic Ultrasound 1:7(2013)

Acknowledgements - This research was performed within the framework of the Center for Translational Molecular Medicine (www.ctmm.nl), project VOLTA (grant 05T-201) and within the framework of the European Commission project iPaCT (FP7 603028).

Figure 3: T2-images acquired at the start of the sonication (A), during sonication (B and C) and 17min post sonication (D). Calculated color-coded T2-maps are shown as overlays in a selected region. Hyper-intense regions (white arrows) are the result of previous sonications.