In vivo validation of T2-based MR thermometry in adipose tissue layers for HIFU near-field monitoring

Paul Baron[1], Mario Ries[1], Martijn de Greef[1], Roel Deckers[1], Max Köhler[2], Jukka Tanttu[2], Chrit T.W. Moonen[1], and Lambertus W. Bartels[1]
[1]*Image Sciences Institute, University Medical Center Utrecht, Utrecht, Utrecht, Netherlands,* [2]*Philips Healthcare, Vantaa, Vantaa, Finland*

Introduction:
High intensity focused ultrasound (HIFU) treatment of uterine fibroids and of lesions in liver and breast is complicated by the risk of undesired near field heating, which potentially leads to cutaneous/subcutaneous tissue damage. In particular adipose tissue layers are at risk due to the lower specific heat capacity and lower heat conductivity compared to those in aqueous tissues. Since the commonly used PRFS-based MR-Thermometry method is unsuitable for measurements in these areas, we evaluated dynamic T_2 mapping for monitoring the temperature [1] decrease in adipose tissue during the cool down period of the treatment cycle. The feasibility of this approach was investigated for liver HIFU ablation in an in vivo porcine model.

Methods:
Ex vivo T_2 temperature calibration: Four porcine subcutaneous abdominal fat samples were extracted directly post-mortem, placed in a 50 ml cylindrical holder and placed in a temperature stabilized closed circuit water bath located in a 1.5T MRI scanner (Achieva, Philips Healthcare, Best, The Netherlands). The sample temperature was independently recorded with a fiber optic probe (Luxtron, Lumasense Technologies, USA). At four temperatures between 25 and 45 °C, T_2 maps were acquired both during heating and cooling. To ensure a homogeneous temperature distribution, T_2 maps were acquired after the temperature stabilized for at least 15 minutes. One coronal slice was acquired with the following imaging protocol: dual echo Turbo Spin Echo, TE_1 and TE_2 are 38 and 180 ms, TR = 2000 ms, TSE factor= 40, voxel size = 1.75x1.75x5 mm^3 with Spectral Presaturation with Inversion Recovery (SPIR) water suppression and a duration of 16s per image. The T_2 maps were calculated assuming mono-exponential decay of the modulus signal so that T_2 based on two measurements is calculated from: $T_2 = (TE_2 - TE_1)/\ln(S(TE_1)/S(TE_2))$, where $S(TE)$ is the modulus of the signal at echo time TE. To increase the SNR, 16 voxels of the T_2 maps were averaged.

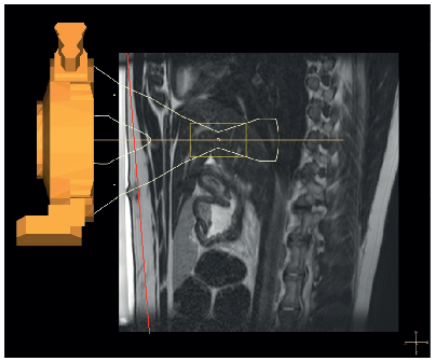

Fig.1. In vivo sonication of the pig liver. The orange line shows the location of the T_2 mapping slice.

Ex vivo porcine HIFU experiment: To verify the temperature change in the near field during a HIFU sonication, an ex vivo experiment was performed. Directly after sacrifice, a section of the subcutaneous adipose tissue was removed and installed under a sonication target on a clinical MR-HIFU system (Sonalleve, Philips Healthcare, Helsinki, Finland) so that the HIFU beam-cone intersected with the adipose layer. During a sonication with 10W of acoustic power for 1000s, coronal dynamic T_2 maps (parameters as above) were acquired in the adipose tissue. In addition, the temperature in the center of the beam path was monitored with a fiber optic probe (Luxtron). The temperature change was calculated for every voxel based on the average of the calibrated T_2 temperature coefficients and compared with the fiber optic measurements.
In vivo experiment: To investigate the in-vivo feasibility of T_2-based thermometry in adipose tissue, the temperature change in the subcutaneous adipose tissue layer of one pig was monitored during a liver sonication. Fig 1. shows a sagittal planning view with the ultrasound target area, beam path, and transducer overlaid on a T_2-weighted image. The pigs were in prone position, sedated, and mechanically ventilated. An acoustic power of 300 W was used for 20 s in an 8 mm diameter volumetric ablation cell. The applied power level and duration had previously been found sufficient to give a lethal thermal dose in a defined region in the liver. During sonication, dynamic T_2 maps were acquired in the subcutaneous fat layer. The T_2 change was converted to temperature change using the average calibrated T_2 temperature coefficient.

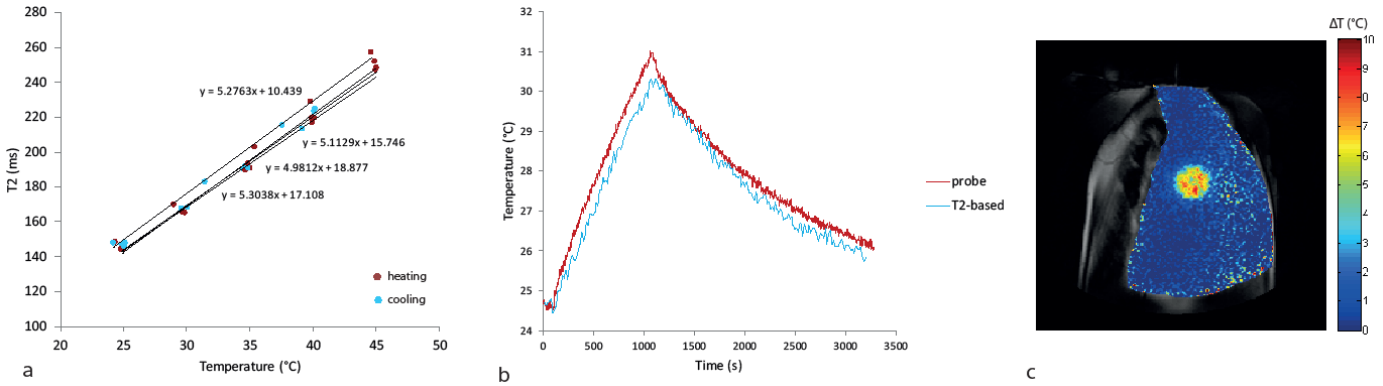

Fig. 2. a) Calibration curves for the 4 pig samples showing the measurements during heating (red dots) and cooling (blue dots) b) Temperature versus time for the probe (red line) and T_2-based temperature (blue line) for one voxel. c) Peak temperature map overlaying a T_2-w background image during the in vivo experiment.

Results:
Ex vivo T_2 temperature calibration: For all samples, a linear T_2 dependence (R^2 >0.99) with temperature was found as shown in figure 2a. The mean T_2 –temperature coefficient found was 5.2±0.2 ms/°C. Reversible T_2 changes were found for all samples after heating the samples to 45 °C.
Ex vivo porcine HIFU experiment: The comparison between the reference temperature (optic probe) and T_2-based thermometry is shown in figure 2b. The accuracy was found to be better than 0.9°C for the entire duration of the sonication.
In vivo porcine HIFU experiment: During the sonication and the subsequent cool-down period T_2-thermometry allowed observing the temperature change due to near-field heating in the adipose tissue with a thermometric precision of 1.1°C (range 0.2-3.8°C).

Discussion & Conclusion:
The reversibility and linearity of the T_2-temperature dependence of adipose tissue allowed to continuously monitor the temperature in the subcutaneous tissue layers in near real-time during cool-down. The temperature change and precision showed heterogeneities, likely reflecting the varying water/fat fractions in a voxel. The cooling time can be expected to be geometry and subject specific, and underlines the need for individual observation of the cool down process to avoid cumulative heating of subcutaneous tissue. Future studies need to explore the inter-individual variation of the T_2-temperature dependence and confirm this dependency at other field strengths.

References: 1. S. Ghandi et al. 6th Annual Meeting of ISMRM, Australia, 1998. Abstract 701