

Near-field management during MR-HIFU ablation in highly perfused organs

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Purpose MR-guided high intensity focused ultrasound (MR-HIFU) ablation in highly perfused abdominal organs requires high acoustical powers to overcome the efficient heat evacuation in these organs. A consequence of this is the risk of thermal damage to tissues in the near-field (between transducer and target area) due to accumulation of heat from individual sonications throughout the treatment. The purpose of this study was to develop a strategy for near-field management during MR-HIFU ablation in highly perfused organs. External tissue cooling was employed to limit the risk of thermal damage, while T2 thermometry was used to monitor near-field temperatures throughout the ablation procedure.

Methods In porcine liver (n=7), a tissue volume of up to 12 ml was ablated using 7 – 10 individual sonications (respiratory-gated, 450W, 20 – 30 sec each), using a modified clinical 1.5T Sonalleve MR-HIFU therapy system (Philips Healthcare, Vantaa, Finland). After each sonication a T2 thermometry scan was performed (dual echo TSE, TR=2000ms, TE1=38.4ms, TE2=180ms, resolution 1.76x1.76x5mm). Temperature maps were calculated relative to a reference scan which was performed at the start of the experiment¹. T2-based temperatures from a ROI in the near-field fat were compared to T2-based temperatures from a control ROI in unheated fat and fiber optic probe measurements (n=2).

Results Sagittal T2 thermometry imaging revealed a steep temperature gradient in the subcutaneous fat layer (figure 1), with skin temperatures of $\pm 20^\circ\text{C}$. Liver tissue ablation without near-field damage was feasible when sufficient cool-down time was allowed (figure 2). T2-based temperatures in the control ROI, i.e. in unheated fat, remained stable ($<1^\circ\text{C}$ change) throughout the treatment in six animals but showed an increasing temperature offset of $<4^\circ\text{C}$ in one animal.

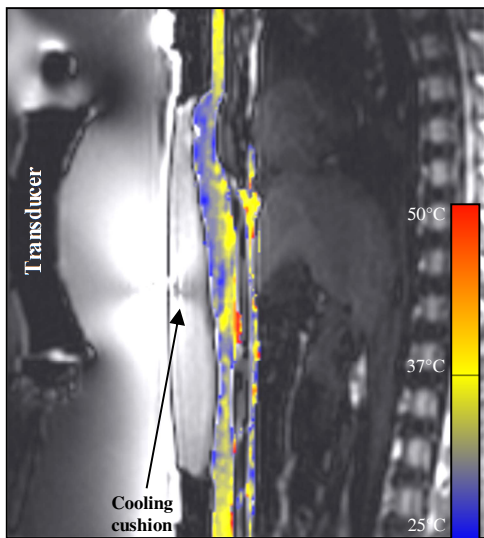
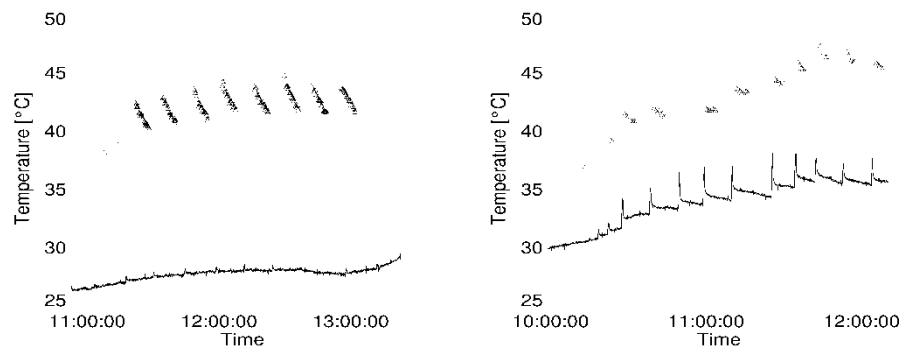


Figure 1 (left): T2 thermometry (sagittal slice), showing the temperature gradient in the subcutaneous fat layer which was induced by the active external cooling system.

Figure 2 (below): Near-field cool-down from two experiments. On the right, accumulation of heat causes a gradual increase of near-field temperatures during the course of the treatment. On the left, a steady state is reached, i.e. no heat accumulation ($\Delta = \text{T2-based temperature measurements in a ROI in the near field}$). Line = fiber optical probe temperature measurements in the fat layer. Note that the probe on the right was positioned deeper, resulting in higher temperatures).



Discussion Many authors have proposed methods for predicting near-field damage due to accumulation of heat such as calculating the predicted energy density per surface area. However, the accuracy of these methods is severely limited by their reliance on modeling of heat diffusion and acoustic pathways, which requires substantial assumptions, and by inter-individual differences such as thickness of the tissue layers, perfusion differences, angle of the acoustic pathway, and depth of the focal point. For these reasons, we propose a combination of active external tissue cooling for protecting the skin and T2 thermometry for real-time monitoring of the heat build-up throughout the treatment. With this, re-sonication intervals can be adjusted according to real-time measurements of accumulated heat, thus limiting the risk of thermal damage while optimizing the total treatment time. This method works regardless of patient-dependent properties such as thickness of the fat layer and sonication depth. In conclusion, heat accumulation in the near-field during MR-HIFU ablation can be managed effectively by using a combination of T2 thermometry in the fat layer throughout the treatment and active external tissue cooling to protect the skin.

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Reference 1: Baron P, Ries M, Deckers R., e.a. *In vivo T2-Based MR Thermometry in adipose tissue layers for HIFU near-field monitoring*. Magn Reson Med, accepted.