

Evaluation of a clinically feasible treatment protocol for MR-HIFU liver tumor ablation in a porcine liver model

Joost W. Wijlemans¹, Mario Ries², Martijn de Greef², Gerald Schubert³, Max Köhler³, Mika Ylihautala³, Lambertus W. Bartels², Maurice A.A.J. van den Bosch¹, and Chrit T.W. Moonen²

¹Department of Radiology, University Medical Center Utrecht, Utrecht, Netherlands, ²Image Sciences Institute, University Medical Center Utrecht, Utrecht, Netherlands, ³Philips Medical Systems MR, Vantaa, Finland

Purpose MR-guided high intensity focused ultrasound (MR-HIFU) can potentially be used for non-invasive image guided thermal ablation of liver tumors. However, the requirement to ablate highly perfused liver tissue while preserving the low-perfused tissue layers in the near field limits the sonications to short high-power bursts, that have to be followed by sufficient cool down time. As a consequence, the ablation of large volumes will be time consuming and challenging in the clinical setting. In this study, we evaluated a clinically feasible treatment protocol for the ablation of unobstructed liver tumors using a porcine liver model. Three treatment outcome variables were assessed: I) size of the ablated region, II) duration of the treatment, and III) safety of the treatment.

Materials and methods After approval by our institution's animal experimental committee, general anesthesia was induced in one Daland land pig and the animal was positioned on a clinical 1.5 T Sonalleve MR-HIFU therapy system (Philips Healthcare, Vantaa, Finland). Before ablation, a T2-weighted 3D TSE scan and a T1-weighted high resolution FLASH scan were made for treatment planning. The location for the ablation was chosen such that it was unobstructed by the ribs (i.e. in the middle liver lobe). The treatment target was to create a non-perfused volume (NPV) with a diameter of at least 10 mm at a depth of 18 mm into the liver parenchyma. All treatment cells (volumetric, 4 mm diameter, 450 W, 23 sec) were sonicated using respiratory-gated thermometry (proton resonance frequency shift technique) and respiratory-gated sonications, based on a navigator beam placed on the diaphragm. The thermal dose estimate of the induced necrosis was subsequently compared to the non-perfused volume assessed with a gadolinium enhanced, dynamic T1-weighted scan. Post mortem, the liver and the soft tissues in the HIFU beam path were macroscopically examined for thermal damage. The thermal damage on coronal liver slices was also compared to the NPV and the thermal dose based necrosis estimate.

Results Post ablation, the maximum diameter of the NPV on coronal slices was 13 mm (~ 2.2 ml). Total treatment time (preparational imaging, treatment planning, ablation, post-treatment imaging) was 135 minutes. Ablation time was 95 minutes, including the cool down phases of ~ 10 minutes between the ablations. Each of the seven respiratory-gated sonications resulted in a duty cycle of 60 - 70%. On post-mortem examination there was no evidence of thermal damage in the HIFU near field except for very limited edema in the muscle tissue of the abdominal wall. The exterior of the liver showed evidence of hemorrhaging and tissue necrosis, but the fibrous liver capsula remained intact. Histological tissue damage, as seen on the coronal liver slices, correlated well to both the NPV on the contrast enhanced scan and the thermal dose based necrosis estimate.

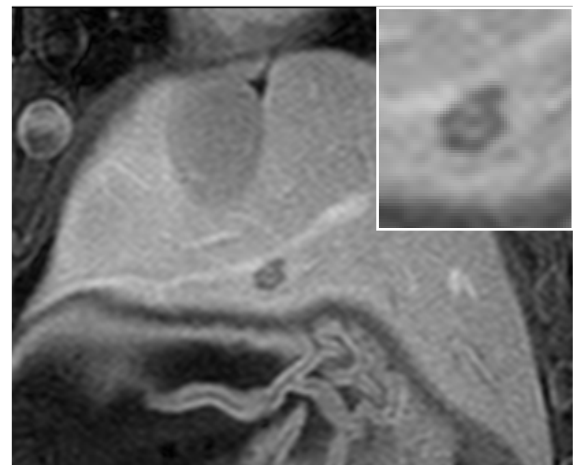


Figure: the contrast-enhanced scan shows the non-perfused volume after ablation (coronal).

Discussion Although MR-HIFU ablation is a promising technique for ablation of colorectal liver metastases, the duty cycle of this technique is a limiting factor when ablation of larger volumes is required. In addition, the high perfusion of the liver requires a high acoustical power output, which can cause thermal damage to the soft tissue in the acoustical beam path. Here, we have shown that it is feasible to perform MR-HIFU ablation of hepatic tissue with a NPV of ~ 2.5 ml volume (at a rate of ~ 1.5 ml/h), without significant collateral soft tissue damage and within a clinically acceptable time frame. These results provide valuable information for the advancement towards a clinical trial. Upcoming experiments will focus on the robustness of this treatment protocol and the impact of inter-costal sonications on ablation efficiency.

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