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Visualization of Spatially and Temporally Heterogenous Thermal Washout in the Application of MR-HIFU Hyperthermia

Question

We report results from the in-vivo application of a previously published model predictive control (MPC) algorithm for MR-HIFU hyperthermia. The purpose of the investigation was to test the controller's in-vivo performance and behavior in the presence of heterogeneous perfusion.

Methods

Hyperthermia at 42 °C was induced and maintained for up to 30 minutes in a circular section of a thermometry slice in the biceps femoris of German landrace pigs (N=5) using a commercial MR-HIFU system and a recently developed MPC algorithm. The correlation of the heating power allocation with heat sink maps and the locations of blood vessels visible in contrast-enhanced MRI images was investigated. The temporal change in perfusion was estimated based on the power required to maintain hyperthermia.

Results

The controller performed well throughout the treatments with an absolute average tracking error of 0.27±0.15 °C and an average difference of 1.25±0.22 °C between T10 and T90. The MPC algorithm

allocates additional heating power to sub-volumes with elevated heat sink effects, which are colocalized with blood vessels visible on contrast-enhanced MRI. The perfusion appeared to have increased by at least a factor of approximately 1.86 on average.

Conclusions

The MPC controller generates temperature distributions with a narrow spectrum of voxel temperatures inside the target ROI despite the presence of spatiotemporally heterogeneous perfusion. This is made possible by the rapid thermometry feedback available with MR-HIFU and the flexible allocation of heating power. The visualization of spatiotemporally heterogeneous perfusion presents new research opportunities for the investigation of stimulated perfusion in hypoxic tumor regions.

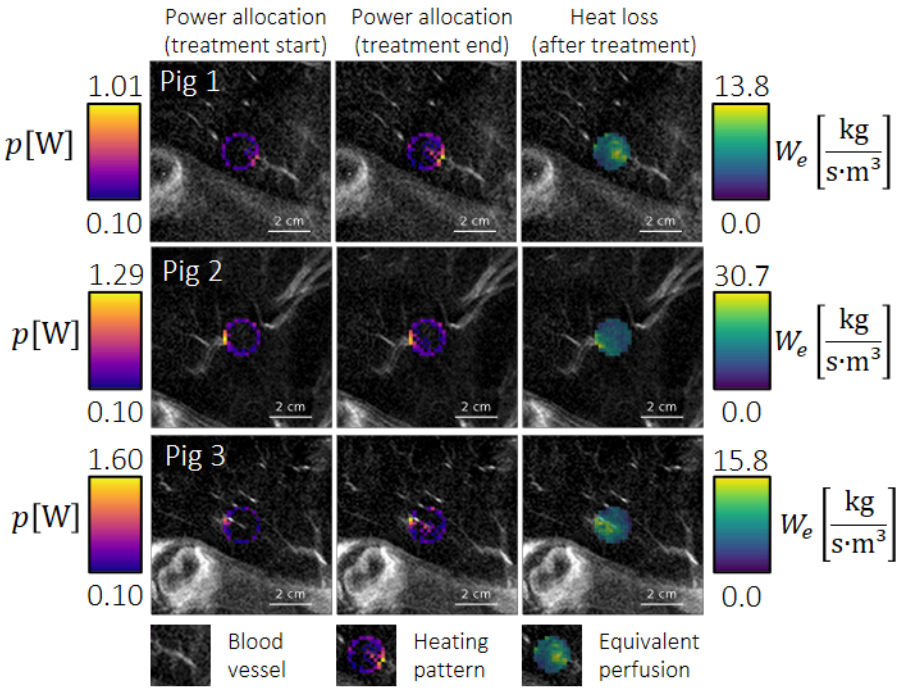

Figure Caption

Overlay on contrast enhanced MRI images of the respective anatomical region for three example MR-HIFU hyperthermia treatments: Average power application pattern during the first minute after warmup (leftmost column), during the last minute before HIFU shutdown (middle column), and equivalent voxel perfusion during the first minute of cooldown (rightmost column).