

Feasibility of Cardiac-Gated 3T MRI-Guided Myocardial Ablation with High Intensity Focused Ultrasound

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Objective: This study sought to determine the feasibility of myocardial HIFU ablation under MRI guidance using cardiac-gated energy delivery schemes.

Background: Invasive catheter-based myocardial ablation has become an important treatment of hypertrophic cardiomyopathy (HCM) and cardiac arrhythmias, but has known complications as well as the inability to actively visualize and control the extent of ablated tissue. High-intensity focused ultrasound (HIFU) can noninvasively create focal ablation lesions and has been developed for multiple non-cardiac clinical applications. MRI, in addition to imaging of myocardial pathology, can provide image guidance of HIFU targeting and potentially allow monitoring of myocardial temperature during ablation. To address the issue of cardiac motion, we investigated the feasibility of ablating ex-vivo myocardial tissue under MRI guidance with several energy delivery schemes to simulate cardiac gating.

Methods: A commercially available MRI-guided HIFU ablation system (Insightec Ltd., Tirat Carmel, Israel) was used on a 3T MRI scanner (GE Healthcare, Milwaukee, WI). Ex-vivo porcine hearts (N=5) were immersed in water at room temperature (23°C) and degassed for approximately 30 min. The first set of experiments (N=3) tested the ability to ablate myocardial tissue in the septum of ex vivo hearts. MR scout imaging was performed to identify and guide the myocardial treatment areas. Multiple HIFU ablation lesions were formed using acoustic powers between 60-90 Watts and continuous sonication for 20s at a HIFU frequency of 1.1 MHz. In a second set of experiments (N=2), cardiac gating was simulated. In Experiment 2A, HIFU pulses at 150W were activated at 1Hz (simulating a heart rate of 60 bpm), with duty cycles ranging from 100% to 10% (corresponding to HIFU pulse widths from 1000ms down to 100ms). The total sonication time was kept at 20s, so the total energy delivered decreased by 90% for the 100ms pulse width. In Experiment 2B, the total delivered energy was kept constant as the pulse width was decreased by increasing the total sonication time. For all experiments, MR thermometry was performed during lesion formation to verify correct ablation location and achievement of thermal ablation threshold (>55°C). T1-weighted imaging was used to image lesions post-ablation. Ex-vivo hearts were dissected to confirm lesion location and directly measure lesion size (at plane of maximal area) from the gross pathology specimens.

Results: In the first set of experiments, ablation lesions were formed in the ventricular septum of ex-vivo porcine hearts (Figure 1). The total area of ablated tissue could be increased by performing multiple adjacent HIFU pulses. In Experiment 2A, lesion size decreased substantially with the shorter pulse width/lower duty cycle (Figure 2). This is likely due to both the reduced total energy delivery and the increased time duration between HIFU pulses. Importantly, a pulse width of 200ms (i.e., duty cycle of 20%) could still create focal lesions of 1mm², but no lesions were seen with 100ms pulse width. In Experiment 2B, there was a less dramatic reduction in lesion size as the total energy delivery was kept constant (Figure 2), showing that increasing the time duration between pulses has a substantial effect on lesion size.

Conclusions: MRI-guided HIFU is feasible on ex-vivo myocardium using a 3T MR-HIFU system. Focal ablation lesions in the septum could be created under cardiac gating conditions, with lesion size decreasing substantially with HIFU pulse width. Further work is needed develop a system for animal testing and ultimately clinical translation.

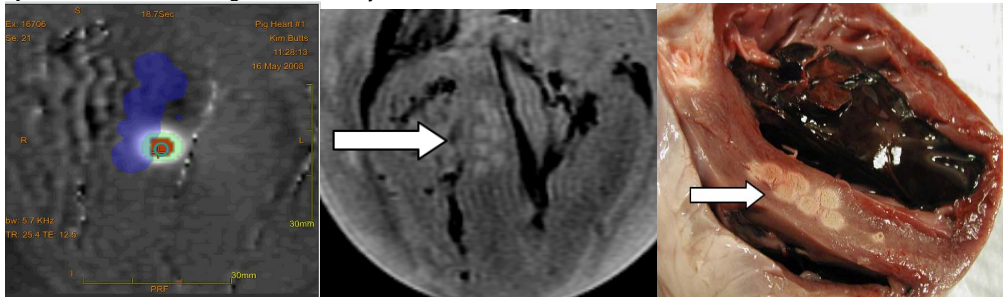


Figure 1: A) MR-temperature map during HIFU septal ablation (Red area indicates a 70°C threshold level and the blue area represents previous sonications), B) T1 MR image of HIFU lesions in ex-vivo septal wall, C) Gross pathology of septal lesions from (B) showing multiple adjacent 20s lesions.

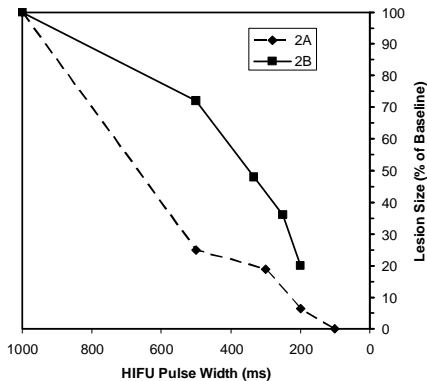


Figure 2: Decrease in lesion size (from baseline) as pulse width is decreased. The decrease is less for Experiment 2B, where total sonication time is increased to keep energy delivery constant.