Detection and exploitation of acoustic cavitation for enhancement of MR guided High Intensity Focused Ultrasound heating in ex vivo liver

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Purpose/Introduction

High Intensity Focused Ultrasound (HIFU) is increasingly used for the non invasive treatment of pathological tissue. The efficiency of heating can be increased by generation of acoustic cavitation in order to modify the local distribution of ultrasound pressure that can be visualized with Magnetic Resonance Acoustic Force Imaging (MR-ARFI). This studies analyzes the change in local tissue displacement with MR-ARFI in *ex vivo* liver tissue in absence/presence of acoustic cavitation. The consequences of cavitation on heating efficiency is investigated with MR-thermometry.

Material and methods

HIFU sonications: HIFU sonications were performed in *ex vivo* liver samples with a MR-compatible HIFU platform (Philips Sonalleve MR-HIFU [1]) under MRI guidance with an Achieva 1.5T scanner. The MR-ARFI sequence consisted of a modified spin echo sequence including a pair of bipolar rectangular gradients [2] of 5 ms duration (each lobe) and 40 mT/m amplitude, with a 1x1x1.5 mm3 voxel size, 80 X 80 matrix, TE/TR= 53/1000 ms. HIFU pulses of 5 ms were synchronized on the first lobe of each gradient pair, with acoustic power in the range of 100-300W. MR-thermometry was performed with the proton resonant frequency shift method using a segmented echo planar imaging sequence (11 k-space lines acquired/TR), 1.34x1.56x2.5 mm3 voxel size, 55x64 matrix size, TE/TR=18/300 ms. The HIFU protocol consisted of a reference sonication at 30W acoustic power during 20 s. Then, a short (0.2 to 0.5 s) and intense (600 to 800W) HIFU pulse was applied to locally generate cavitation. Finally, a second HIFU sonication identical to the reference was repeated to compare heating efficiency in presence of cavitation. These three sonications were performed under MR thermometry. MR-ARFI was performed before and after each sonication to visualize potential changes of the acoustic field due to thermal and/or cavitation effects. A minimum delay of 5 minutes between each sonication was used to ensure complete cooling of the tissue.

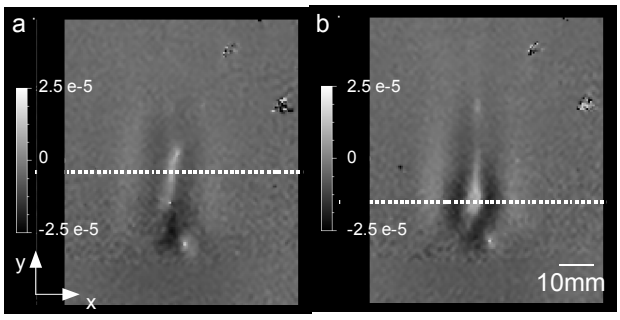

Figure 1: displacement maps (in m) obtained from MR-ARFI data, (a) before sonication and (b) after the second sonication (800W, 0.5 s). White dashed line shows y coordinate of maximum

Results

Figure 1a shows displacement maps from MR-ARFI before sonication. The area displacement is elliptic with a maximal displacement amplitude of 15 µm. The reference heating showed a maximal temperature increase of 12°C (Figure 2a and 2c). MR-ARFI data acquired after cooling demonstrated identical displacement distribution and amplitude. The HIFU pulse (800W, 0.5 s) resulted in a maximal temperature increase of 20°C. The MR-ARFI data acquired after this pulse revealed a modification of the shape (referred as a "tadpole shape" in [3]) of the displacement map at the focal region, with a 7 mm shift of the location of the peak displacement toward the transducer with increased maximal value to 20 µm and enlargement in the direction perpendicular to the ultrasound propagation (Figure 1b). The maximal temperature increase of the last HIFU sonication reached 17°C (Figure 2b and 2c) and confirmed the "tadpole" shape previously observed in MR-ARFI (Figure 1b). MR-ARFI data acquired after this sonication showed identical displacement image as after the cavitation pulse (Figure 1b).

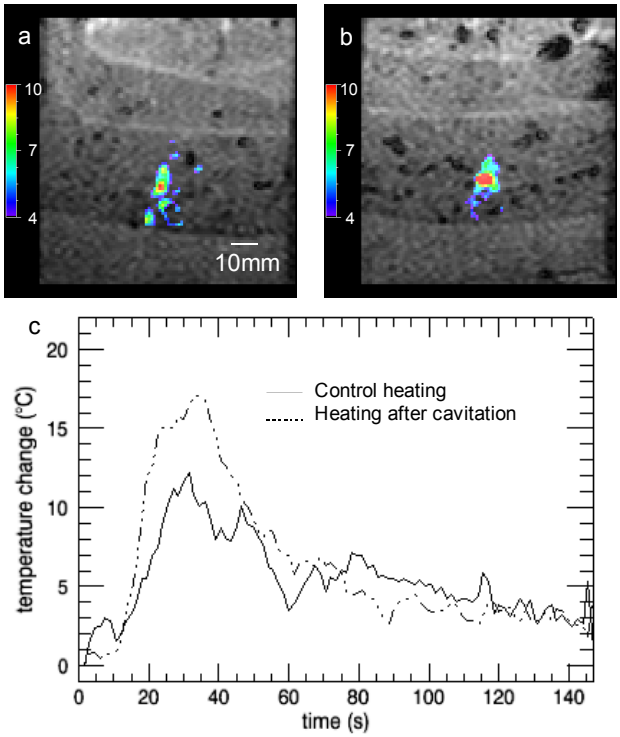

Figure 2: MR temperature data for the two sonications performed at 30W during 20s. Image (a) is for the reference sonication and image (b) for the sonication performed after the cavitation pulse. Graph (c) plots the temperature evolution for both conditions at the pixel showing maximal temperature increase in images (a) and (b)

Discussion

MR-ARFI and MR-thermometry data showed coherent results. As reported previously in rabbit muscle, a tadpole shape of the acoustic beam was observed in ex vivo liver tissue in presence of cavitation with a shift toward the transducer. Modification of the acoustic properties due to cavitation could be visualized and quantified with MR-ARFI. The presence of cavitation resulted in a 50% enhancement of the maximal temperature with identical sonication parameters, in agreement with results reported by Coussios in gels [4]. Combination of MR-ARFI and MR-thermometry may help in providing a better control of cavitation effects in the liver for enhancement of MR guided HIFU thermal ablation and to protect organs located in the far field of the beam path[5].

References

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