inter-costal liver ablation under real-time MR-thermometry with partial activation of a HIFU phased array transducer

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Purpose/Introduction

The partial obstruction of the High Intensity Focused Ultrasound (HIFU) beam by the rib cage complicates the treatment of liver tumours. To reduce the risks of inducing collateral damages such as skin burns [1], a method for selective deactivation of the transducer elements located in front of the ribs is proposed. The effectiveness of the method is demonstrated *ex vivo* and *in vivo* in the liver of pig with real-time MR thermometry.

Material and methods

Selection of the elements to deactivate: Proton density weighted 3D gradient echo MR-imaging was performed prior to sonications (TE/TR=4.6/8.6 ms, 1.8x1.8x3 mm^3 voxel size). The HIFU transducer was mechanically positioned below the targeted point and a manual segmentation of the bones included in the beam path was performed. The resulting mask was projected on the transducer surface by ray tracing from the focal point. The elements with more than 50% obstruction of their active surface were deactivated. The total processing time for the projection was 80 sec. *Ex vivo validation :* for each experiment (N=3), a sample of porcine rib bone and liver was sonicated with a MR (1.5T) compatible Philips HIFU platform (256 elements transducer). Two sonications (0.5 Wac/element during 30 seconds, with/without deactivation) were performed at the same location at 5 cm depth in the liver through the rib cage. The temperature evolution was monitored in two orthogonal orientations (a vertical slice observing the temperature at the targeted point and along the propagation cone, and a horizontal slice observing the temperature in the HIFU near field below the bones) with real-time MR thermometry (segmented EPI with an echo train length (ETL) of 5, TE/TR=22/200 ms, 1.5x2.5x6 mm^3 voxel size). *In vivo validation :* for each animal (N=3), two sonications (1Wac/element, 20 seconds duration) were performed at at the same location (4.5 cm depth in the liver). The anesthetized animal was positioned in right decubitus on top of the HIFU platform. A single shot EPI was acquired with an ETL of 59, TE/TR=23/200, 60° water selective binomial excitation, 2.72x2.68x6 mm^3 voxel size, 1 sagittal slice below the ribs and one coronal slice centered on the focal point. The experiments were performed while breathing and motion related MR-thermometry artifacts were compensated with a multi-baseline phase correction [2]. The pixels on the temperature images displaying a low SNR were masked out.

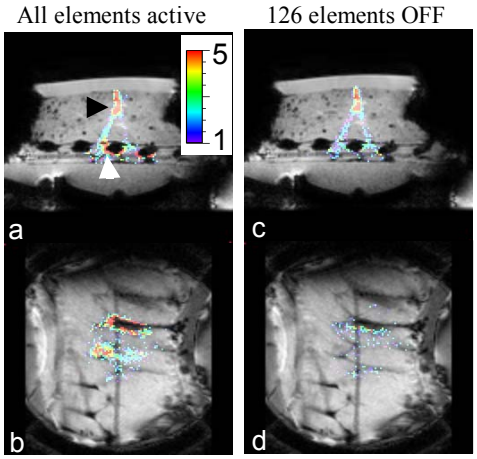

Figure 1: temperature images at the end of the HIFU heating with all the HIFU transducer elements (left) and with partial deactivation (126 elements OFF). The temperature scale is displayed on the right of image (a)

Results

Figure 1 shows the temperature images without/with partial deactivation of the HIFU transducer (126 transducer elements were selected by the proposed method). A similar temperature increase (7°C) was observed at the focal point (black arrow head in Fig. 1a) for both conditions, indicative of the absence of loss of the heating efficacy at the focal point when the elements were deactivated. The temperature increase near the bone (white arrow head in Fig. 1b) was higher (15°C) for the sonication with all the elements than for the sonication performed with the elements deactivated (4°C). The temperature image displayed in Fig. 1C shows a localized heating in soft tissue below the bones. Amost no temperature increase near the bone was visible in the experiments performed with deactivation of the elements (Fig. 1d). **Figure 2** shows the results of MRgHIFU sonications performed *in vivo* in the liver of a pig (124 elements were selected by the proposed method). Very similar temperature curves are observed at the focal point for both conditions (Fig 2a), with a maximal temperature increase of 16°C followed by a rapid cooling due to perfusion and thermal diffusivity. An important reduction of the temperature increase was observed in pixels located near the bones when the 124 elements were deactivated. The temperature increased during the 20 sec HIFU sonication and the following 30 sec, indicative of heat diffusion from the bones toward the surrounding soft tissues. For both conditions, the temperature reached a nearly constant plateau over the remaining observation period. The image of the mean temperature (Fig. 2b) between 100 sec and 200 sec displays an important increase around the bone included in the beam path (Fig. 2b). A reduced and spatially homogeneous temperature increase was observed when the 124 elements were deactivated (Fig. 2c).

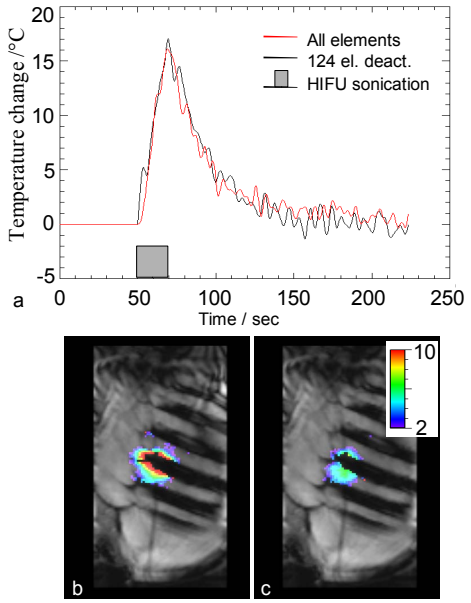

Figure 2: temperature data obtained *in vivo*. The graph in (a) shows the temperature evolution in the liver at the focal point with all the elements active (red curve) and with deactivation of 124 elements located in front of the bones (black curve). The rectangle indicates the timing of the HIFU sonication. Images b and c show maps of the mean temperature increase after the end of the HIFU sonication, with all the elements (b) and with deactivation of the 126 elements (c). The

Discussion

This method for selective deactivation of the transducer elements located in front of the ultrasound obstacles provides a practical solution to avoid heating of the bones and the surrounding tissues during HIFU sonications, without reduction of the heating efficacy at the focal point. It shows promising results for inter-costal MR guided HIFU ablations, without requirement of partial rib resection and therefore offers an increased safety for the patient.

References

1-Wu F *et al*. Ultrason Sonochem 2004;11(3-4):149-154.
2-de Senneville BD *et al*. Magn Reson Med 2007;57(2):319-330.