A method to improve transcostal MR-HIFU sonication in presence of electronic beam steering

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Introduction

Transcostal high intensity focused ultrasound (HIFU) ablation could provide a non invasive solution for the treatment of liver cancer and cardiac arrhythmias. Due to the high acoustic absorption of the bones, a significant increase of temperature in the ribs and surrounding tissue can be observed. Several methods have been proposed to minimize the energy deposition around the bones: surgical resection of a section of the ribs [1], time reversal technique [2], insertion of reflective strips [3] on the skin in front of the bones, electronic deactivation of transducer elements located in front of the rib (so called "binarized apodization law") [4, 5, 6]. However, electronic steering of the beam is generally required during thermal ablation in order to achieve large ablation volumes and/or to compensate target displacement due to respiratory motion. In this study, we sought to demonstrate the necessity of an update of the binarized apodization law when using HIFU beam steering.

Material and methods

Experiments were performed at 1.5 T with the Sonalleve MR-HIFU platform (Philips Healthcare, Vantaa, Finland) operating at a frequency of 1.2 MHz. A rib phantom was created by embedding porcine ribs (Fig 1b and 1d) in a gel (2% agarose, 3% silicon). A 3D proton-density weighted gradient echo sequence (TR/TE/FA=4.6/8.57ms/15°, FOV=350×350×180 mm^3, voxel size=1.8×1.8×3 mm^3) was acquired to localize the ribs within the phantom. After selection of the targeted focal location in the gel and manual segmentation of the bones on the resulting 3D images (using an in-house developed software), the binarized apodization law was calculated. For this purpose, the shadow of the bone was geometrically projected onto the transducer surface and each transducer element covered by more than 50% was deactivated. Sonications (51 acoustic Watts during 30 sec) with lateral electronic steering (7 mm right or left from the natural focal point) were performed. For each location, one sonication was performed using the **initial** law (i.e. by projecting the shadow from the natural focal point, see Fig 1a) and one with the **updated law** (i.e. by projecting the rib shadow from the actual targeted point, see Fig 1c). Sonications were monitored by real time MR-thermometry (PRF shift technique) using a multishot EPI sequence with the following parameters: TE/TR=12/200ms, FOV=200×200 mm^2, matrix=100×98, flip angle=20°, echo train length=7, 3 adjacent slices of 2.5 mm thickness positioned in the transverse orientation. Pixels, with a low SNR on modulus images in the ribs, were masked out in temperature images.

Results

Figure 1 (images b and d) shows the temperature maps obtained with initial and updated laws when focusing 7 mm right from the natural focus. The maximal temperature increases (figure 2) at the focal point/near the rib were 19°C/17°C (initial law) and 28°C/9°C (updated law). Sonication perfomed with 7 mm left electronic deflection resulted (data not shown) in maximal temperature increases of 20°C/8°C (initial law) and 26°C/7°C (updated law), respectively.

Conclusion

This study shows that transcostal sonications using electronic beam steering (in the range of the respiratory motion amplitude, 14 mm) may benefit from the update of the binary apodization law. With this method, a gain in temperature increase at the focal point of 30% to 47% was observed, while rib heating was reduced by 12% to 47%. This geometric projection method only requires the acquisition of one set of anatomical images and the segmentation of the bones has only to be performed once. Therefore, this method is simple to implement and may significantly improve safety and efficacy of the procedure.
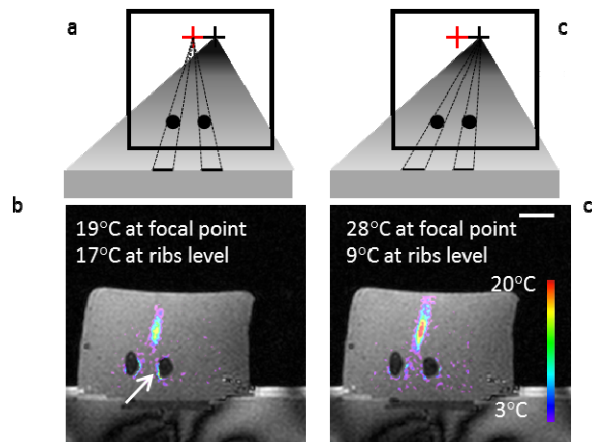

Fig 1. Transcostal sonications with 7 mm right deflection from the natural focal point with the initial law (a,b) and with the updated law (c,d). Diagrams at the top (a, c) illustrate the projection method. Images in b and d show the measured MR-temperature maps, overlaid on modulus images at the end of sonication. The horizontal white bar on images (d) represents 30 mm and temperature scale is displayed on (d) the white arrow in (b) shows the pixel selected for temperature evaluation near the rib.
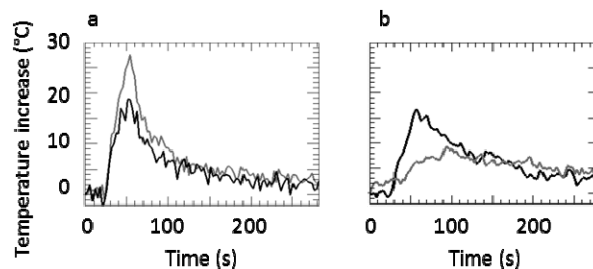

Fig 2.Temperature evolution measured at the focal point (a) and near the ribs (b) during sonications performed at 7 mm on the right of the natural focal point, with the initial law (black curve) and with the updated law (grey curve). The pixel indicated by the white arrow on figure 1b was selected to plot the temperature evolution near the rib.

References

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