Fast simultaneous temperature and displacement imaging during HIFU ablation in swine liver

Pierre Bour[1], Fabrice Marquet[1], Solenn Toupin[1,2], Matthieu Lepetit-coiffé[2], and Bruno Quesson[1]
[1]*L'Institut de RYthmologie et de Modélisation Cardiaque, Bordeaux, Aquitaine, France,* [2]*SIEMENS-Healthcare, Saint-Denis, Île-de-France, France*

Target audience: MR scientist with interest in MR guided High Intensity Focused Ultrasound in liver

Purpose:

MR guided High Intensity Focused Ultrasound (MRgHIFU) allows non-invasive thermal ablation of soft tissues such as the liver while providing real-time guidance and monitoring [1]. Encoding both tissue displacement (ARFI) and temperature (PRF method) in the phase of a MR image has been proposed with the aim of measuring maximal temperature changes during short ultrasound pulses [2],[3],[4]. The aim of this study was to develop a sub-second fast acquisition sequence with the objective of monitoring tissue mechanical changes with temperature during ablation process and to validate its applicability *in vivo* during MR-HIFU ablation of swine liver.

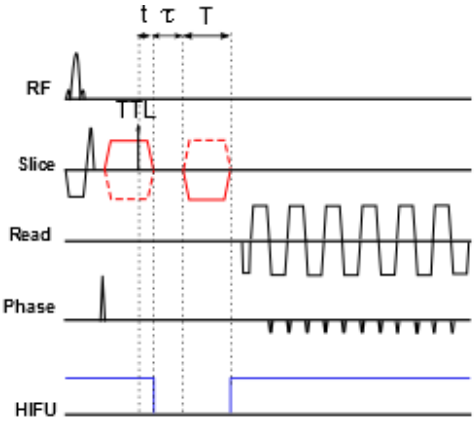
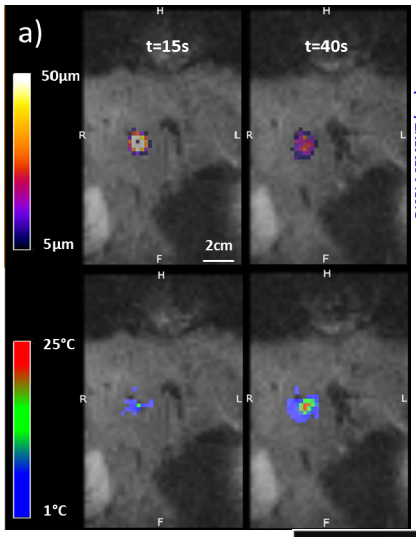


Figure 1: Single-shot GRE-EPI MR-ARFI/thermometry sequence.

Material and methods:

A single-shot gradient echo Echo Planar Imaging (FOV 94x150mm², 4 slices, 4 saturation slabs encompassing the FOV, TE/TR/FA=28ms/500ms/40°, echo train length of 40, spatial resolution of 2.3x2.3x5mm^3, with fat saturation) sequence was modified (Fig.1) to incorporate two gradients (vertical orientation, T=4ms duration and 25mT/m amplitude with opposite polarities) before the echo train. This motion-encoding gradient pair was alternated in polarities in subsequent dynamic acquisition to add/subtract motion and temperature information in the phase images (ϕ_n^+ and ϕ_{n+1}^- respectively). HIFU sonication was applied continuously (transducer composed of 256 elements, 13/13 cm aperture/focal, operating at 1 MHz) and interrupted during the second gradient using TTL synchronisation (t=1ms) in order to encode tissue position changes with respect to the first gradient. An additional adjustable delay (τ=1.2ms) was introduced between the two gradients to allow mechanical relaxation of tissue after stopping HIFU sonication. The images were streamed and processed online on a separate workstation to compute temperature $T \propto ((\phi_n^+ - \phi_{ref}^+) + (\phi_{n+1}^- - \phi_{ref}^-))/2$ and displacement $D \propto ((\phi_n^+ - \phi_{ref}^+) - (\phi_{n+1}^- - \phi_{ref}^-))/2$ (with ϕ_{ref}^- and ϕ_{ref}^+ phase reference images) [2] images and display them as color overlays onto magnitude images. The method was evaluated *ex vivo* on chicken muscle and then *in vivo* in the liver of a swine under general anaesthesia. Typical HIFU sonication parameters were 30s at 350W (electric). *In vivo* sonications were performed under breath hold with MR-ARFI/thermo slices positioned on the liver in coronal orientation. 3D T1-weighted flash sequence was performed after HIFU ablation and prior to euthanasia of the animal for liver dissection.



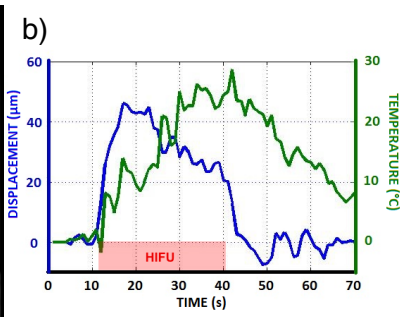


Figure 2: in vivo real-time MR-ARFI/Thermo data. a) Displacement (top) and T (bottom) coronal images obtained at t=15s (top) and at the end of heating period t=40s (bottom). b) Time course of D (blue) and T (green) at the focus.

Results:

Ex vivo data showed that displacement at the focus decreases from 34 to 17µm while relative temperature increases from 0 to 48°C. *In vivo*, the maximal temperature increase was 28±1.2°C at the end of the sonication (Fig. 2) and displacement values decreased from 45µm to 22µm at the end of sonication with a standard deviation of 2.2µm during apnea. Post-ablation images (fig. 3) showed a hyper intense signal at the targeted location and liver sample dissection confirmed the presence of the thermal lesion (7x10mm in dimensions).

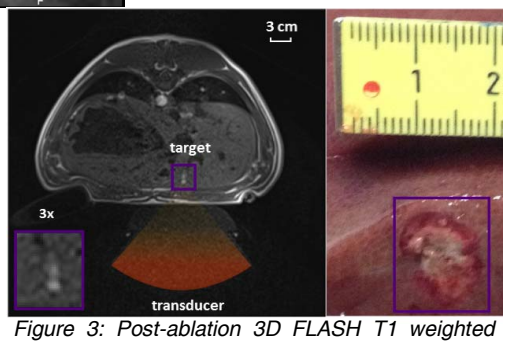


Figure 3: Post-ablation 3D FLASH T1 weighted image (left). Picture (right) of the thermal lesion after liver extraction.

Discussion and conclusion:

The proposed method allows simultaneous quantitative monitoring of temperature change and tissue micrometric displacement during HIFU sonication in the liver of a swine at a frame rate of 1 Hz for each of the 4 slices. Encoding displacement in temperature sensitive sequence resulted in negligible loss of the HIFU duty cycle (95.1%) and increase in echo time by 9.2ms. Real-time assessment of tissue properties change associated to temperature increase may provide additional relevant information for predicting the extent of the thermal lesion and irreversible tissue damage in complement to the calculation of the thermal dose.

References :[1]Wijlemans et al. Investigative radiology 2014 ; [2]Auboiroux et al. MRM 2012 ; [3]Viallon et al. ISMRM 2010 ; [4]Souchon et al. MRM 2008