Local Hyperthermia with Focused Ultrasound (FUS) or Interstitial Laser Applicator (LITT) under PRF-based MR-Temperature Monitoring in the Living Kidney of the Rabbit

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ABSTRACT. Tissue movement during the respiratory cycle could be a severe problem for the PRF-based MR-thermometry. This study demonstrates that real-time temperature monitoring in rabbit kidney is feasible with 1°C accuracy, space resolution of 1.25 x 1.25 x 4 mm and actual temporal resolution of 4.3 sec/ 3 slice volume. Both minimally-invasive (LITT) and non-invasive (FUS) methods were used to induce local hyperthermia. FUS allowed to target any location within the kidney volume. LITT was used to deliver a lethal thermal dose in the kidney cortex. The registrated temperature evolution correlated well with the MRI follow up of the lesion and post-mortem histological analysis.

OBJECTIVE. 1. To demonstrate the feasibility of PRF-based MR-thermometry in-vivo kidney using minimally invasive (laser) hyperthermia and 2. using noninvasive FUS heating.

INTRODUCTION. Real time monitoring of temperature evolution in hyperthermia procedures is mandatory to guarantee a predefined thermal dose. PRF-based MR-thermometry in moving targets (i.e. organs that are displacing during the respiratory cycle) is challenging. The approach described here allows a precision of the real-time temperature measurement in-vivo on the order of 1°C in the rabbit kidney. On the other side, FUS method permits to induce a local hyperthermia in a non-invasive way, under the condition of an accessible acoustic window. This study demonstrated the FUS advantage to target any location within the rabbit kidney.

MATERIALS AND METHODS. Experiments were performed on a Intera (Philips) clinical scanner. Real-time PRF-based MR-thermometry of the living kidney was performed using a respiratory gating (with the standard equipment of the scanner) and a segmented FFE/EPI sequence (3 slices, slice thickness 4 mm, interslice gap 0.5 mm, 128 x 128 mm FOV, 96 x 96 matrix size, 15 k-space lines/TR, TR = 226ms, TE = 20ms, flip angle=35, gate delay=300ms, gate width=477ms, 80% scan percentage, total time per volume 4.3sec for a respiratory cycle length of 1.8 sec). Relative phase was converted in temperature variation on a pixel-to-pixel base. Animal anaestesia was induced using 15mg/kg Zoletil intramuscular and maintained using a 5 l/min air flow with 0.5% to 1.0 % Fluothan. In order to avoid ghost artifacts caused by visceral motricity this was temporarily blocked using 0.2 ml/kg of Visceralgin injected intramuscularly.

FUS equipment consisted of a 14-element spherical transducer (LEP, Paris, France, curvature radius 80 mm, aperture diameter 96 mm), that can be hydraulically moved along the OX and OZ axes. The focal length can be electronically adjusted in the range

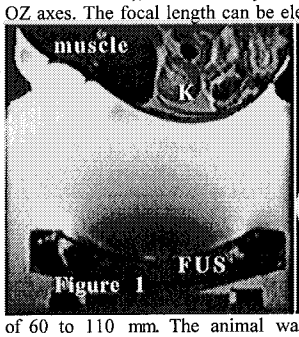


Figure 1

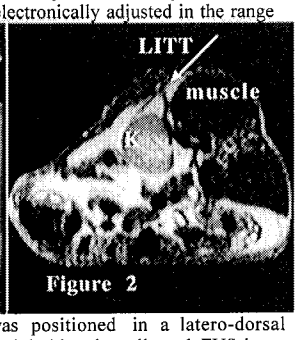


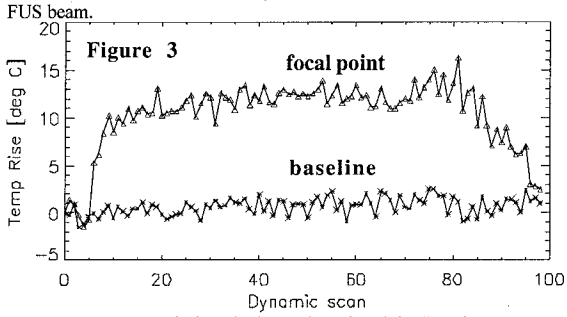
Figure 2

of 60 to 110 mm. The animal was positioned in a latero-dorsal position in an in-house constructed holder that allowed FUS beam propagation to the rabbit left kidney (K) throughout the aperture of a circular surface coil. As visible in Figure 1, the FUS propagation pathway only included the skin, the dorsal muscles and/or fat tissue, avoiding any bones or intestine. MR-thermometry slices were positioned perpendicularly to the FUS beam axis (coronal).

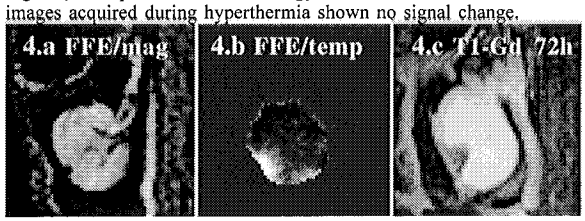
Interstitial laser induced hyperthermia was obtained using a IR laser (Dornier), operated in continuous wave mode at 10W power for 6 sec followed by a waiting time of approximately 20 sec. The optical fiber was equipped with a light diffuser tip that was positioned inside a catheter sheath. The catheter was previously inserted close to the kidney within the fat tissue (on the opposite side to the renal sinus) without injury to the kidney capsule or visceral tissue. Figure 2 shows an example of catheter position. MR-thermometry slices were positioned perpendicularly to the optical fiber.

RESULTS AND DISCUSSION. 1. Phase stability and precision of temperature measurement: standard deviation of temperature baseline as directly calculated from MR data (respiratory gating and standard reconstruction) was always better than 2°C, down to 0.8°C. Small phase oscillations with low spatial frequencies were noticed preferentially along the FH direction. Theses oscillations could be removed using a high-pass filter applied to the temperature map (Fourier transformation, k-space weighting, back Fourier transformation). The filter was shown to not affect significantly the precision of temperature measurement in the case of a highly localized temperature distribution (i.e. fixed focal point FUS hyperthermia). The precision of temperature measurement could be improved down to 0.5 °C standard deviation.

2. FUS induced hyperthermia: The available acoustic power allowed an average temperature rise up to 12°C. Figure 3 shows the focal point temperature evolution as registrated during a constant power (44W) FUS induced hyperthermia experiment, compared to the temperature baseline in a voxel that was not heated. The entire volume of the kidney was shown to be accessible to the FUS beam.



3. Laser induced hyperthermia (Fig.4): the measured temperature shown a radial distribution around the diffuser tip with a maximum increase of approximately 30°C at the kidney border. Figure 4.b shows an example of calculated temperature map together with the corresponding FFE magnitude image (4.a). Registrated temperature evolution correlated well with MR follow up (T1-Gd, Fig 4.c) and post-mortem histology. Note that intermitent T1-w images acquired during hyperthermia shown no signal change.



CONCLUSION. In-vivo PRF-based MR-thermometry and FUS access to the kidney were shown to be feasible on the rabbit model.

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