Feasibility of multipolar radiofrequency ablation in the pig liver under simultaneous real-time MR thermometry

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Introduction MR thermometry has been recently used to monitor bipolar (with two electrically active zones) radiofrequency ablation (RFA) of liver tumours and to predict the size of the thermal coagulation volume from the accumulated thermal dose (1). Multipolar radiofrequency RFA with temporal cyclic alternation between electrode pairs (up to 15) offers a mini-invasive approach for the treatment of large hepatic tumours with an average diameter of 5 cm of more (2). In this work we demonstrate the feasibility of simultaneous MR temperature monitoring during multipolar RFA performed *ex vivo* and *in vivo*.

Material and Methods

RF procedure A 475-kHz RF generator (Celon/Olympus, Teltow, Germany) was used with 3 (ex vivo) and 6 (in vivo) MR compatible bipolar RF needles of 1.5 cm length. In order to achieve larger ablation zones, the connection was modified for *in vivo* experiment so that each needle had only one active zone of 3 cm length. With the multipolar operation mode, the power application alternated every 2 seconds between the 15 possible couples of electrodes. As the tissue resistance along the electrical path between a given pair of electrodes increased with temperature, these electrodes were activated less frequently during the procedure (multipolar resistance-controlled application of power, RCAP). Each transmission line of the generator was filtered against EM interferences as previously described in (3). However, the switching between the pairs of electrodes is specific to the multipolar approach and may cause additional interferences.

Ex vivo study Three electrodes were inserted in a pig liver at an average distance of 3 cm and nominal power was applied for 13 minutes yielding a total energy of 36kJ. Simultaneously, MR imaging was performed with four different slice orientations using a RF-spoiled gradient echo sequence accelerated with an EPI read-out train length of 9. Image parameters included: 4-channel body surface coil, water selective excitation, FOV = 200 x 200 mm^2, spatial resolution = 2 x 2 x 5 mm^3, TE/TR/FA= 10 ms/21 ms/15 °, temporal resolution (4 slices) = 830 ms. Phase images were transferred in real time to an external PC, and temperature and thermal dose (TD) maps (1) were calculated in real time with the proton resonant frequency shift method (1) with dedicated software. MR post-procedural imaging was performed with a 3D T1-weighted gradient echo sequence (FOV 200 x 138 mm^2, voxel size = 1.5 x 1.5 x 1.5 mm^3, TE/TR/FA = 3.4 ms/8 ms/15°).

In vivo study Six RF electrodes were inserted under ultrasound guidance in the liver of a healthy pig (85 kg) under anaesthesia and assisted ventilation (20 cycles per minute). Two distinct ablation zones were targeted in separate procedures. Real-time MR thermometry was performed with respiratory gating and FOV = 300 x 225 mm^2, spatial resolution = 3.1 x 3.1 x 5 mm^3, TE/TR/FA= 15 ms/37 ms/25°. The second procedure lasted 28 minutes yielding a total energy 164 kJ. Then, 25 slices T1-weighted gradient echo images with water selective excitation were acquired (FOV 350 x 262 mm^2, spatial resolution= 1.6 x 2 x 5mm^3, TE/TR/FA = 5.4ms/61ms/80°). After sacrifice of the animal, the liver was excised and fixed with formalin. Macroscopic views of the RF thermal coagulation zone were obtained after 5 mm thick slicing of the entire liver in the orientation perpendicular to the RF electrodes.

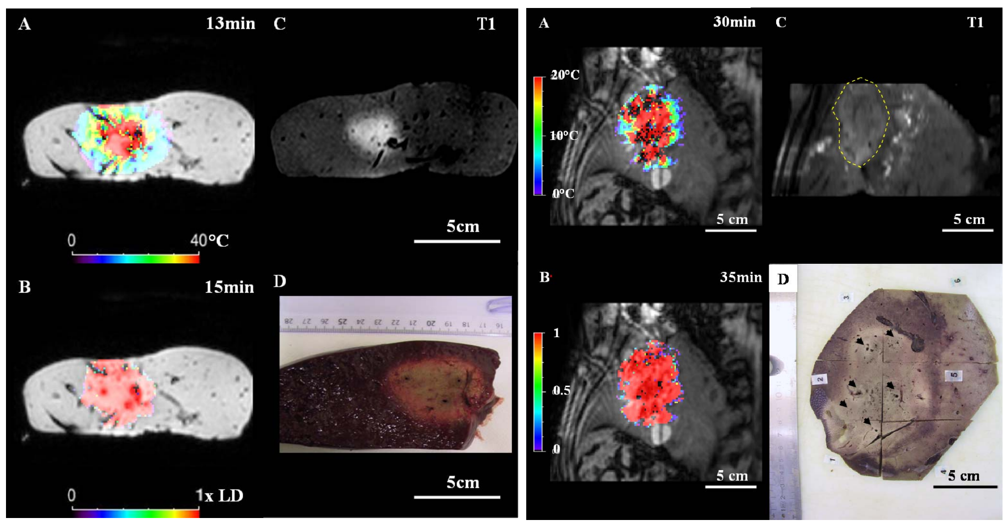

Figure 1. *Ex vivo* (left) and *in vivo* (right) studies: **A)** MR temperature maps at the end of the RF application. **B)** Thermal dose maps at the end of the procedure. The Lethal dose threshold (LD) was set equivalent to a constant heating at 43°C during 240 min. **C)** T1w images acquired after the RF ablation **D)** Macroscopic views of the thermal coagulation zone.

Results Fig. 1 (left) shows the *ex vivo* temperature and thermal dose maps at the end of the procedure, as well as the T1 and histological evaluation of the thermal coagulation zone, which demonstrate a homogeneous macroscopic lesion of 4 x 3 x 3 cm^3. Fig. 1 (right) shows the *in vivo* results, with a resulting homogeneous macroscopic lesion of approximately 9 x 7 x 4 cm^3. No significant SNR degradation was observed during the application of power, despite the iterative switching between the electrodes.

Conclusion MR thermometry can be used for the real-time intra-procedural monitoring of multipolar RF ablation procedures for the thermal coagulation of large (of the order of 250 cm^3) volumes in the pig liver *in vivo*. The quality of the real-time thermal dose maps appears satisfactory for acquisitions in the presence of respiratory motion and switching between the different pairs of electrodes. The large thermal coagulation volume is spatially homogeneous as predicted by the real-time thermal dose images and confirmed by the post procedural MR images and histology.

References (1)Terraz S et al Eur Radiol. 2009 Sep 16. (2) Seror O et al. Radiology. 2008 Jul; 248(1):288-96. (3) Lepetit-Coiffe M. Et al. Eur Radiol. 2009 Aug 6.