MR-Mediated Radio Frequency Ablation

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Introduction

Thermal ablation by radiofrequency energy is a minimally invasive procedure used routinely to treat various lesions, for example non-resectable liver tumors. Ablation probe guidance is conducted most commonly by ultrasound or contrast-enhanced CT, with treatment planning and monitoring accomplished with CT or MRI. Commercial radiofrequency ablation (RFA) devices typically employ a 500 kHz generator connected to the patient via a large grounding pad against the skin, and a sharp probe inserted percutaneously into the tumor. Ohmic heating in the high current density near the sharp tip produces tissue damage which leads to killing of the tumor. In this new method, MR-Mediated Radio Frequency Ablation (MR-RFA), the MR scanner not only provides image guidance for RFA probe placement, it also supplies the RF energy for heating. Potential advantages include elimination of the ground pad (a source of burns) and RF interference with the scanner. Additionally, the scanner enables interprocedural tumor localization, probe placement, RF power control, temperature mapping and tissue monitoring. The MR-RFA coupling device and probe can be completely disposable, and no additional generator is required.

Materials and Methods

The coupling device which picks up RF energy from the scanner was a length of 26 gauge Teflon insulated wire taped along the edges of both sides and the end the patient table (about 800 mm total length) of a Siemens Avanto 1.5 T scanner. The wire was connected to a Sprague 80-turn high voltage adjustable ceramic capacitor to fine tune the wire length to resonance at 64 MHz. The other end of the wire was connected to the RFA applicator, which consisted of a 3 mm diameter hollow brass needle with a solid sharp tip. Inside the needle bore was placed a Luxtron fiber optic temperature sensor to permit continuous recording of tip temperatures. The entire length of the needle except for the last 2 cm was insulated with Kynar shrink tubing. Initial testing was performed on a nickel sulfate-doped agar gel phantom or bovine liver tissue specimens. To image temperature in these materials, a single 5 mm slice phase sensitive 128 x 128 GE image with TR=24 ms, TE=10 ms was obtained before and after applying a heating sequence (typically a high RF duty cycle GE or TSE sequence for 1 min). The pixel by pixel difference between the unwrapped phase images yielded an image of temperature.

Two healthy domestic Yorkshire swine were anesthetized with ketamine/xylazine for induction, intubated, and maintained on isofluorane while supine in the scanner. ECG, respiration rate, pO_2, and pCO_2 were monitored. Following a series of scout images for anatomic localization of the liver, a small incision was made in the skin of the upper abdomen with a scalpel, and the RF applicator was inserted percutaneously so that the tip entered the liver (Figure 2). A one or two minute heating pulse sequence was performed, with recording of the tip temperature. Then the animals were sacrificed, and the livers harvested, sectioned and photographed. Because respiratory gating was not used and the animals were free breathing, phase images were not of sufficient quality to reconstruct temperature maps.

Results and Discussion

Accurate temperature maps (within ±2 °C of the fiber optic temperature) could be obtained in the gel phantom and liver specimens. The heating rate could be varied with RF duty cycle (or SAR), yielding heating rates of as much as 4 °C/s, and temperatures approaching 100 °C in the gel. Temperatures in liver specimens usually peaked around 50-80 °C due to coagulation at the applicator tip. Coagulation was evident when the time-temperature curve reached a plateau and became unstable. Liver sections revealed thermal lesions on the order of 1 cm in diameter.

Conclusions

A standard MRI scanner can serve as an effective generator for RF ablation by means of a very simple, disposable device. Power deposition is controlled by the pulse sequence. MR-mediated RFA eliminates the use of external RF generators that must be made MR compatible, and achieves rapid controlled tissue heating. Thermal lesions in the livers of live pigs were successfully created.

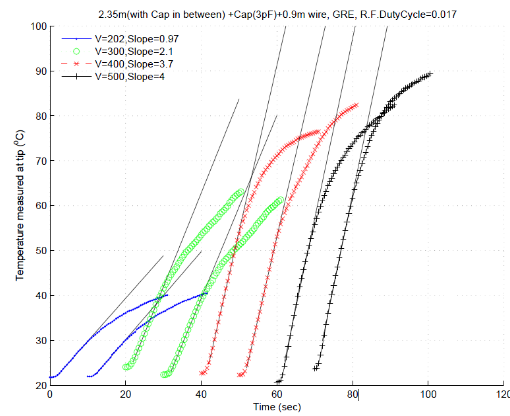

Figure 1. Heating curves in agar gel phantom, up to 4 °C/s, max 100 °C. Heating rate varies with RF voltage (or equivalently, duty cycle or SAR).

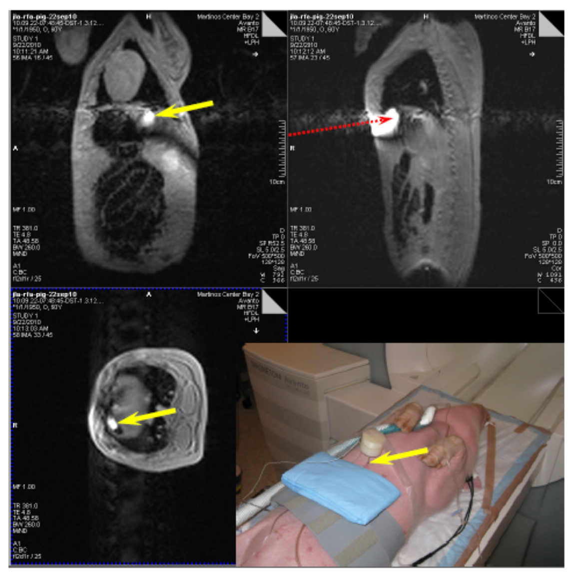

Figure 2. Three anatomic scans of a live pig. Bright image spot is RFA applicator tip artifact (yellow arrows); Red: Needle track. Lower right: applicator (yellow arrow) inserted through the chest into the liver under MR guidance.

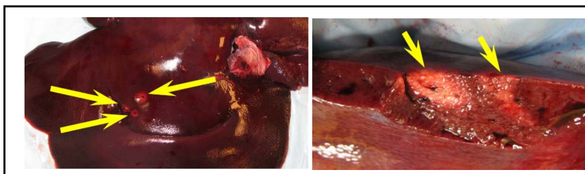

Figure 3. Thermal lesions in the pig liver produced by the RF ablation depicted in Figure 2.