Novel Body Coil Driven Radio Frequency Ablation Device

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INTRODUCTION

Thermal ablation by radiofrequency (RF) energy is a minimally invasive procedure used routinely to treat various lesions, most notably non-resectable liver tumors. Ablation probe guidance is done most commonly by ultrasound, and treatment planning and monitoring by 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. This study explores the use of RF ablation in which the MR scanner provides the RF energy. Potential advantages include elimination of the ground pad, and use of the scanner for tumor localization, probe placement, RF power control, temperature mapping and tissue monitoring. The coupling device and probe could be completely disposable, and no additional generator would be required.

CONCEPT & METHOD

The body coil of the scanner generates circular polarized (CP) magnetic flux density which is used as a source of energy. Like a mechanical rotating electric generator in which a loop of wire cutting through a static magnetic flux density develops an electromotive force (EMF), Fig 1 illustrates how a static wire loop cut by the rotating magnetic flux density generates an EMF. Because the EMF oscillates at a radio frequency, the wire is effectively a transmission line, and its length relative to the wavelength, the dielectric constant and conductivity of the surrounding media and reactances with respect to surrounding structures all become important in determining current flow and standing waves on the line. A separate physical ground path does not need to be provided. By placing one end of the wire into a conducting medium such as tissue, ohmic and dielectric heating can result. The perturbation of the body coil tuning and RF fields can be minimal, such that the tissue may be imaged, and the MRI can be used to monitor the temperature rise with a method such as proton resonance frequency shift (PRFS). Because the wire is electromagnetically coupled to the body coil, it can potentially serve as a local receiver coil itself. Power deposition can be controlled by tuning the line and by varying the RF duty cycle of the pulse sequence. Alternatively, a tuned loop (essentially a surface coil) may be used to capture the RF energy and coupled into the probe tip via a matching circuit and a length of coax.

EXPERIMENT SETUP

A 26 gauge Teflon insulated wire was taped along the edge of the patient table of a Siemens Avanto 1.5 T scanner, looped back around the isocenter, and inserted into an agar gel phantom prepared with normal saline to which a small amount of copper sulfate was added to reduce T_1, as shown in Fig 1. A series capacitor was attached to the wire to tune it . The capacitance did not require adjustment even for variations in wire placement or when the wire was replaced. The insulation at the tip was removed for a distance of about 5 mm. To monitor the temperature near or at the hotspot, a Neoptix Reflex fiber optic temperature probe was taped to the exposed tip of the wire or a short distance from the tip. To image the temperature change throughout the phantom, phase imaging was performed using a brief GRE sequence with TR=138ms, TE=10ms, FOV(phase)=43.8%, resolution=128 before and after applying a heating sequence, typically another GRE sequence with a high RF duty cycle (typical SAR=10% for agar; 25% for ex-vivo liver assuming patient weight to be 150lbs). Temperature maps were created by unwrapping the phase difference between the phase images using a standard algorithm and scaling the resulting maps to represent temperature difference from baseline.

RESULTS & DISCUSSION

Fig. 2 shows the temperature rise at the tip measured with the fiber optic temperature probe in the agar and in ex-vivo bovine liver. The liver tissue requires more power to achieve the same final temperature. Coagulation of protein on the initially clean wire tip in the liver tissue often caused the heating profile to fluctuate. Fig. 3 illustrates the PRFS method to monitor the temperature at the tip of the wire in ex-vivo bovine liver. Although the magnitude image (Fig 3 left) showed significant artifacts due to the presence of the RF applicator, the phase maps were accurate and lead to the correct values for the temperature increase. The thermal image at the center presents the temperature increase when the heating sequence was not performed, showing no temperature increase at the probe location. The thermal image on the right shows a temperature increase of 20 °C following RF heating, which compares well with the fiber optic value of 22 °C.

CONCLUSION

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, and temperature monitoring is readily accomplished via the PRFS method. MR-mediated RFA eliminates the use of external RF generators that must be made MR compatible, and achieve rapid controlled tissue heating that is readily monitored by the scanner.

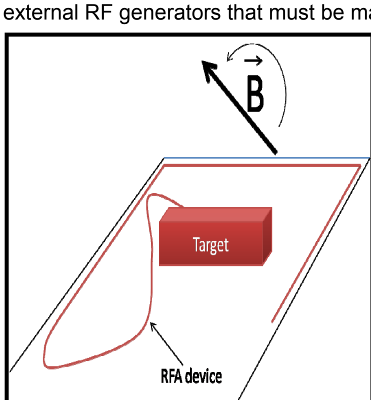

Fig 1. The RFA device and target (e.g., liver or phantom) were placed on the patient bed. Circular polarized magnetic flux density from the body coil cutting the wire of the RFA device generates an EMF which heats the medium.

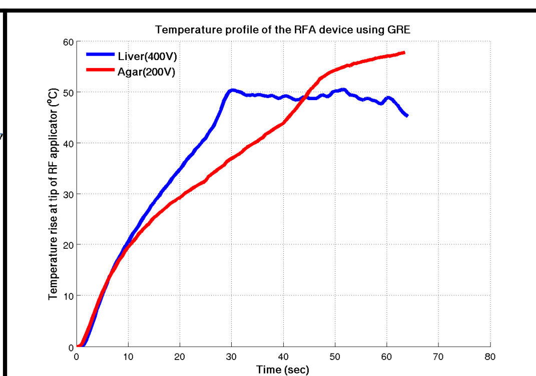

Fig 2. The heating profile of an open ended coaxial probe driven by a 30 cm resonant loop in agar (blue) and a wire in bovine liver (red) measured with the fiber optic temperature probe.

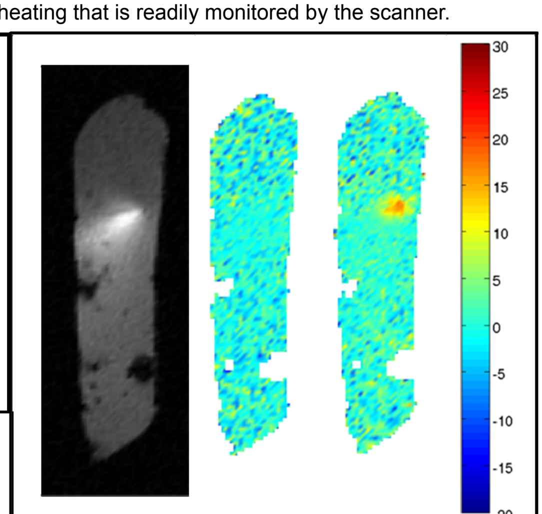

Fig 3. Bovine liver ablation experiment. Magnitude image (left), map of temperature increase with no heating sequence applied (middle), and with a heating sequence (right). The bright artifact in the magnitude image shows the location of the RF applicator.