Simulation of A Novel Radio Frequency Ablation Device within a MR Scanner

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INTRODUCTION

Radiofrequency ablation (RFA) is an established method for treating tumors through heat induced by passage of an electric current through a probe inserted percutaneously into the tissue. Typically, the tumor is imaged by CT or MRI, followed by a separate procedure in which the probe is positioned under ultrasound guidance and the treatment proceeds. Another separate CT or MRI is required to confirm the success of the treatment. The process can be cumbersome and time consuming. By using the MR scanner as the source of the RF energy, all diagnostic, guidance, treatment and monitoring functions can be combined in a single efficient and cost effective procedure. In order to better understand the safety and performance issues, we simulated the operation of a MR-driven RFA device in the body coil of a 1.5 T scanner.

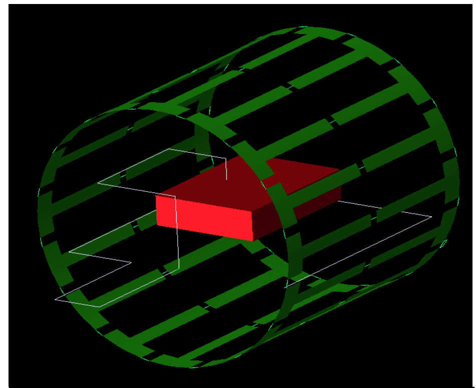

Fig 1. Model geometry showing the RFA device placed within the body coil and the tip inserted into the simulated liver tissue (box phantom).

METHODS

The simulation was carried out using the Remcom, Inc. (State College, PA, USA) XFdtd 7.0 (XF7) 3D electromagnetic simulation software package, which is based on the FDTD (finite difference time domain) method. The modeled body coil had dimensions of 60 cm long and 60 cm diameter, and was a 16 rung highpass birdcage coil (Fig 1). It was first tuned to 1.5 T so that the field within the center of the body coil was homogenous. Then, its performance with a rectangular solid (box phantom) 7 cm tall, 31 cm long, 23 cm wide, with the electrical properties of liver tissue (dielectric constant 70.62, conductivity 0.55 S/m) placed at the isocenter was recorded as a reference. Finally, the RFA device, modeled as a simple wire which captures RF energy from the body coil by electromagnetic induction, was placed in the model geometry with its tip embedded in the box phantom corresponding to our experiments. The RFA device was modeled as PEC (perfect electrical conductor) material. The simulation grid (spatial resolution) was chosen to be 1 cm.

RESULTS & DISCUSSIONS

The unloaded birdcage coil was tuned to 64.178 MHz using 40 pF capacitors on the end rings (S_{11}=-23dB). The |B1+| field contour map, shown in Fig 2, is fairly homogeneous. Fig 3 compared the |B1+| field within the simulated phantom without (left) and with (right) the RFA device. The body coil was highly coupled to the RFA device due to magnetic flux density cutting through the device, resulting in artifact (brightness) usually appearing at the location of the device in experimental images of phantoms or ex vivo liver specimens. The reflection coefficient S_{11} of the body coil changed from -16.2 dB with the phantom to -3.6 dB with the RFA device present. Thus it is expected that the overall field intensity would be lower when the device is present, possibly affecting the operation of the scanner or over-estimation of SAR. However, in experiments the scanner always performed normally and scanning was never interrupted by excessive reflected power. The calculated ratio of the average SAR (based on a 1g average) of the phantom with and without the RFA device was 0.21, indicating that the overall field was lower when the RFA device was present. However, the ratio of the maximum local SAR of the box phantom was 2.65. The maximum local SAR occurs at the tip of the RFA device, demonstrating that the device has a significant energy localizer effect exactly as desired.

CONCLUSIONS

The simulations are limited because (1) a coarse 1 cm spatial resolution was employed, making the RFA device cross section effectively 1 cm^2 (compared to 14 or 26 gauge wires used in experiments); and (2) the body coil model was not based on the true structure of the coil of the Siemens Avanto 1.5 T scanner (because this information is not readily available to us). However, the simulations provided a quantitative and understandable model of the physics in rough agreement with experiment. Although the device may alter the performance of the body coil during the treatment, the change is predicted to be toward safer (lower body SAR) conditions, while focusing energy at the probe tip where it is needed.

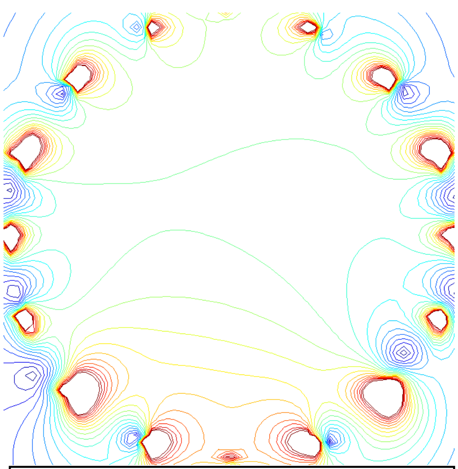

Fig 2. Contour map of |B1+| in the axial slice of the unloaded coil at isocenter. The contour interval is about 10% of the maximum value at the center of the slice.

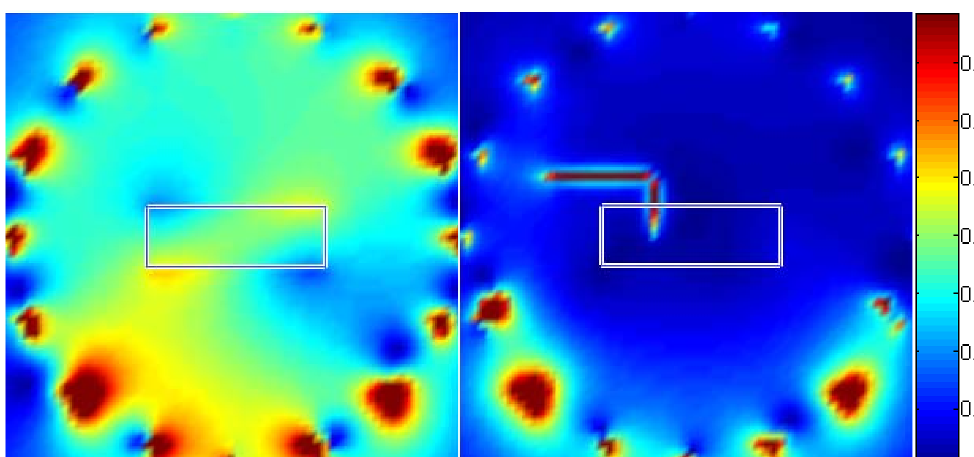

Fig 3. Axial slice of |B1+| with only the liver phantom (left) and with the phantom and RFA device (right). The location of the phantom within the body coil is indicated by the box. The quadrature excitation ports of the coil are at the bottom left and right, making those rung currents larger.