Heating Effects around Resonant Lengths of Wire during RF Excitation

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Introduction

There is a potential safety concern when elongated metallic wires (EEG leads, intravascular guidewires) are present inside the body coil during MRI. A recent study [1] related to actively MR visualized catheters has established that the length of the coaxial cables used with such devices is an important parameter. Guidewires completely in air showed no significant heating [2], but short lengths of copper wire embedded in a conducting-gel phantom did [3]. Safety precautions for the recording of EEG signals during MRI data acquisition have been proposed [4].

We are interested here in the safety aspects of endovascular receiving antennas for high-resolution endoluminal imaging [5,6]. Their coupling to the magnetic component of the transmit RF field is the same as for any other local coil, and will not be addressed here. But the coupling to the electric component poses specific problems, due to the electrical conductivity of the body fluids and tissues immediately surrounding the antenna. The electric field couples to the outer metallic surface of the coaxial signal cable. This coupling can be modelled by a simple straight wire, and some aspects of it can be studied by solving Maxwell's equations for transverse magnetic waves in cylindrical symmetry.

Methods

Straight lengths of varnish-insulated 1 mm dia copper wire were run at R=16.5 cm from the symmetry axis and parallel to it. The midpoint of the wire was always in the transversal midplane of the body coil. One or both ends of the wire were immersed in typically 5 cm of saline, contained in a 13 mm inner dia glass tube, and a fiberoptic temperature sensor (Omega) was attached to the wire end.

We measured the temperature increase after 6 minutes of a Turbo SE sequence on a Siemens Magnetom Symphony with a machine-calculated whole body SAR of 1.75 W/kg.

Results

In Fig. 1, the length of the wire is varied. Both thermometers are outside the body coil, and they were read off sequentially, which explains the difference in the two readings. The wire is electrically free-floating, i.e. completely unconnected. An unvarnished (bare) wire gives similar results. When the midpoint of the wire is not in the midplane of the coil, the heating is less. For wires entirely in air the heating always remains small.

Using a fixed length of wire, and varying the distance R, the rise in temperature is roughly linear in R, and negligible for R=0.

In Fig. 2 only one thermometer is left in place, in 10 cm of saline, and the other end of the wire is either connected to the ground of the input connector of the scanner's Flex Interface, or left free floating. Otherwise, it is the same as in Fig. 1.

When in experiments as in Fig. 1 the length of the saline-filled tubes is increased, the total wire length for maximum temperature rise decreases. With tubes longer than approx. 20 cm, no such length variation is observed anymore.

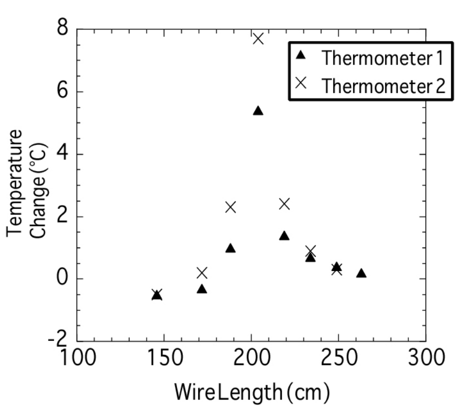

Fig.1

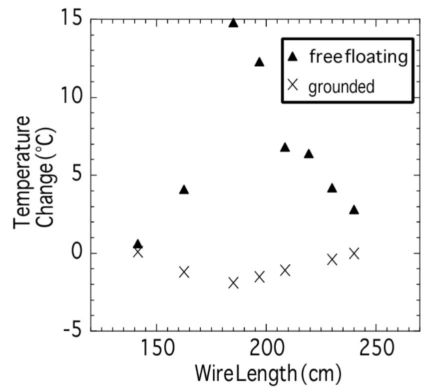

Fig.2

Discussion

In a simplified model of a birdcage resonator, the RF magnetic field rotates in the xy-plane and has everywhere the same value. The RF electric field oscillates in the z-direction (parallel to the static magnetic field), is zero on the axis and increases linearly with distance R. For an RF power that yields a typical 90-degree pulse (about 0.5 ms), the electric field at the edge of the empty tunnel is of the order 1 kV/m.

The the R-dependence of the heating effect shows that it is due to the electric field. Note that the actual value of the temperature increase results from a balance between heat incoming from dissipation, and outgoing by thermal diffusion. Therefore its value cannot be compared between experiments with different geometries.

There is a resonant-length effect for the heating of saline-dipped ends of copper wire, even when the ends are outside the magnet. This "end effect" is associated with currents induced on the central part of the wire. These are maximum when the wire has the length of a short-circuited halfwave receiving dipole, as can be shown from Maxwell's equations. By themselves, however, these currents are of little consequence, since a good conductor like copper dissipates little electrical energy. But, in time-quadrature with the currents, large electrical charge densities appear near the wire tips. Their electric fields point into the saline. The saline, being a poor conductor, dissipates the electrical energy into heat. This dissipation is potentially harmful.

The wavelength in a saline-filled narrow tube is in between that in a large tube and that in air. This probably explains the disappearance of the resonant effect when the saline tube is made longer. A ground connection of good RF quality makes the wire "infinitely long" and suppresses the resonant effect. It is not obvious that this grounding technique should also work with an actual catheter. Work on this question is in progress.

Acknowledgments

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