RF heating comparison between conductive and resistive wires in interventional and endoluminal MRI

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Introduction

In the last few years, the interest for using metallic guide wire and catheter (e.g. nitinol) for interventional MRI or endoluminal MRI coils (e.g. copper) has considerably grown [1,2]. The major issue is to insure patient safety against potential heating of tissues located in the wire vicinity. As this kind of heating has not only been observed at the wire tip, but also along the wire [3], this work investigates the heating along the wire. The two kinds of wire materials were used: a low resistivity wire (copper), and a resistive wire (nitinol). More precisely, the purpose of this paper is to assess the differences between resistive and non resistive wires. In fact, during a MRI experiment, the radiofrequency B_1 magnetic field is accompanied by an electric field E which induces currents (at the same frequency) in the metallic wire placed in the tunnel. The wire will enhance the RF electric field in its close vicinity, and produces a local increase of SAR, leading to a temperature increase of the surrounding tissue. In addition, if the wire is resistive, the induced current will heat the wire itself by Joule effect, leading to an additional tissue temperature elevation caused by heat conduction. A comparison of measured data for the two kinds of wires was conducted in this correspondence. Simulations of both electric field and wire induced currents were also made to assess the experimental data. Simulation results are presented as the estimated temperature elevation around the wire.

Methods

Temperature measurements along metallic guide have been made for λ-lengths wires, where λ is the wavelength in air (4.7 m for ω = 63.7 MHz) of the RF B_1 field. Wire diameter was 0.14 mm, and their electrical resistance was R ≈ 53 Ω/m (nitinol wire) and R ≈ 1 Ω/m (copper wire). They were placed close to the wall tunnel (fig. 1) of a 1.5 T MR Symphony system (Siemens, Erlangen, Germany). To assess the local concentration of E-field, the temperature increase was measured in small pieces of agar-agar gel (0.9 % NaCl, σ = 1, ε_r = 81) placed around the wire. The temperature was measured with an optical fiber system (Luxtron 3204, Luxtron Corporation, Northwestern Parkway, CA, USA). The sensor was mounted adjacent to the wire with Teflon rubber. A 60s True-Fisp sequence (TR/TE = 4.93/2.46 ms, α = 65°) was used to produce RF excitation. To simulate the induced current I and the electric field E, the Hallén's integral equations were solved using Mathematica (Wolfram Research Inc., Champaign, USA) assuming a plane wave excitation (E = 1 V/m, parallel to the wire, propagation direction perpendicular to the wire). For estimating the temperature elevation from simulated values, the following hypotheses were made: for the conducting wire the temperature elevation is proportional to E^2, according to SAR effect, and for the resistive wire, in addition, we have a proportionality to I^2, according to Joule effect. In both cases, wires were excited on a λ/4-length with respect to the experimental case in which the wire is in a 1.20 m tunnel (roughly λ/4).

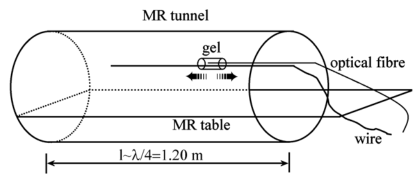

Fig. 1. Schematic experimental setup.

Results

The temperature variations along the wires present different shapes for the two wires. Fig. 2a shows the temperature variation as a function of position along the guide for a λ-length conductive wire and fig. 2b presents the simulated squared electric field in the same conditions. The reference position is the extremity of the wire inside the MRI tunnel. The temperature variation has two minima for λ/4 and 3λ/4, and a maximum for λ/2. Fig. 3a presents the temperature variation along the λ-length resistive wire and fig. 3b the simulated squared induced current. The temperature variation shape shows more minima and maxima then conductive wire case. The minima and maxima succession are given by a combination between SAR and Joule effect. That may be explained by the fact that in this case the temperature elevation is a weighted sum of both SAR and Joule effect. In both cases, measured and simulated values are in agreement.

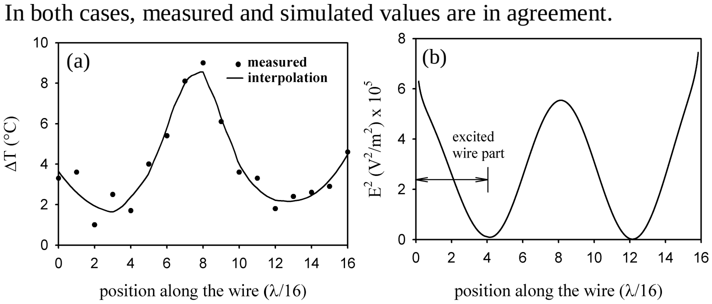

Fig. 2. (a) Measured temperature elevation and (b) Simulated squared electric field along a λ length conductive wire.

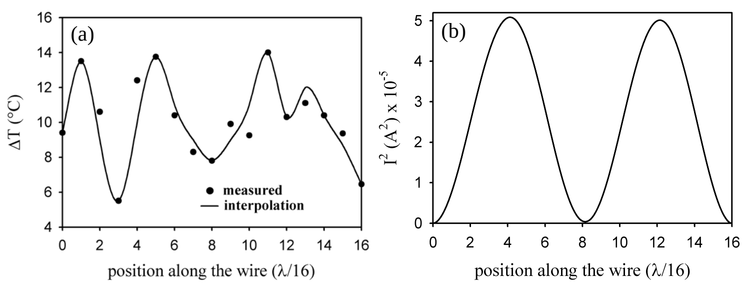

Fig. 3. (a) Measured temperature elevation and (b) Simulated squared current for a λ length resistive wire.

Discussion - Conclusions

For λ length wire, this experiment confirms earlier results [3] concerning the appearance of heating elsewhere than at the wire tip. For metallic wires in MRI, it is clear that two heating mechanisms occurred, according to the wire resitivity. Comparison between simulated E^2 and I^2 shapes and experimental data, shows that the assumptions made concerning heating (for a resistive wire the heating is proportional to I^2 and E^2, and for a conductive wire to E^2) are valid. The fact that the excitation for the simulation is made with a plane wave in a more homogeneous way that it is really in the MRI tunnel could explain local differences between simulations and measures. The conductive case is more favorable by producing less heating. The local concentration of the E field producing SAR around the wire is dominant for conductive wires, whereas for resistive wires the Joule effect increases the heating and changes the shape of temperature variation along the wire. These results are to be take into account for the choice of the material for MRI with respect to safety guidelines.

References

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