A Standard Implant for Determination of Local SAR in Testing of RF-induced Heating of an Implant

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Introduction

A medical implant may result in tissue heating during an MRI scan due to interaction with the RF-magnetic field (B_1)[1]. Non-clinical testing of the potential for tissue heating in the presence of an implant may be performed in a phantom[2]. The heating of the implant will occur due to interaction with the local RF electric field induced by B_1 in the body. For an elongated metallic implant, such as a cardiac or neurostimulation lead, the temperature rise of tissue surrounding the electrode may be expressed as[3]

$$\Delta T = A\left|\int_0^L S_1(z)\, E_{\tan}(z)\, dz\right|^2$$

where A is a constant, S_1 is the electric field sensitivity function of the lead, $E_{\tan}$ is the tangential component of the electric field, and z is distance along the lead, which has a length L and z = 0 is at the electrode. In order to calculate the in-vivo temperature rise based on the phantom measurements, it is necessary to determine the numerical value of the background $E_{\tan}$ in the phantom at the site of the implant. In this work, we describe how measurements of the temperature rise of a standard implant may be used to determine $E_{\tan}$.

Materials and Methods

Figure 1 shows the standard implant, which is a 1/8" × 10 cm ASTM B348-5 titanium rod. We drilled 1 mm diameter holes centered 1 mm from each end perpendicular to the axis and through the rod. Fluoroptic probes were placed in the holes. The physical properties of the rod for the calculations in SI units are K=7.2, Cp = 560 and ρ = 4420. The rod was placed at the side of the rectangular ASTM phantom at a location where the local tangential field is nearly maximal. The phantom material was prepared with 9 gm/*l* poly-acrylic acid gelling agent and 1.4 gm/*l* of NaCl. The conductivity was measured to be about 0.46 S/m. A GE 3T Signa HDx MRI system was used to generate a fast spin echo sequence with a console predicted SAR of 3 W/kg. The landmark was the center of the torso.

Results

A method of moments program was used to determine the SAR distribution in a uniform tangential electric field and a thermal solver that utilized the first order thermal transport equations was used to calculate the time-dependent temperature rise at the ends of the rod. After six minutes of electric field application, the calculated temperature rises at the end of the rod were 1.31 °C/(W/kg) at 64 MHz and 1.45 °C/(W/kg) at 128 MHz. Figure 2 shows an image of two implants in the phantom for measurements at 128 MHz; the rods exhibit distortion due to induced currents. Figure 3 plots the actual measured temperature rises at the ends of the rod at 128 MHz. Also plotted in Fig. 3 is the calculated rise for which a local SAR of 8.9 W/kg, which provides the best fit between measured and calculated temperature rises. Measured local SAR determined by calorimetry with no implant was 8.46 W/kg. Similar good agreement between calculation and measurements was obtained for 64 MHz.

Conclusions

Advantages of using the standard implant over calorimetry for determination of the tangential electric field in non-clinical testing are (1) measurement with the rod yields a greater rise than calorimetry, saving time and reducing error due to temperature probe noise and heat loss to the surroundings and (2) the temperature rise of the rod provides a more precise measure of the electric field along the length of the rod, since calorimetry provides an average of the SAR around the temperature length of the rod, since calorimetry provides an average of the SAR around the temperature probe.

Fig. 1. 1/8" by 10-cm Ti rod with temperature probes

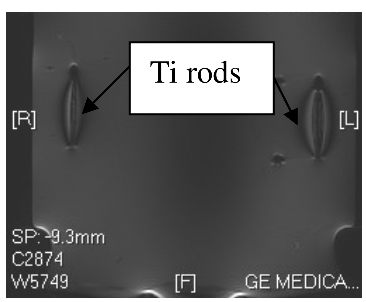

Fig. 2. Coronal image of phantom setup at 128 MHz.

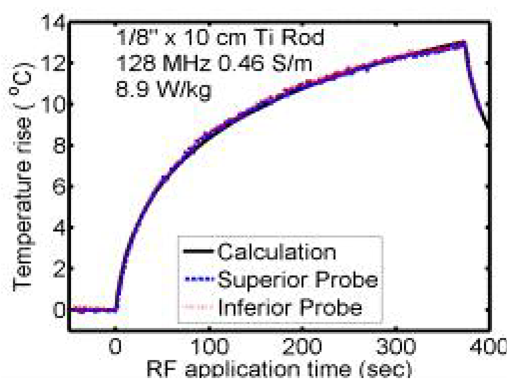

Figure 3. Theoretical and experimental temperature rises vs time at 128 MHz.

1. J.A. Nyenhuis et al. IEEE Transactions on Device and Materials Reliability, vol. 5, pp. 467-480, 2005.

2. Standard Test Method for Measurement of Radio Frequency Induced Heating Near Passive Implants During Magnetic Resonance Imaging, Standard F2182-02a, ASTM International.

3. S.M. Park et al, J. Mag. Reson. Imag., 1278-1285, 2007.