Changing Boundary Conditions: Effects On Catheter Heating

S. O. Oduneye[1], S. Ghate[2], K. J. Anderson[1], and G. A. Wright[1]

[1]Medical Biophysics, Sunnybrook Health Sciences Centre, University of Toronto, Toronto, Ontario, Canada, [2]Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada

Introduction. During an MRI examination, induced radio frequency (RF) currents on electric conductors, such as electrode lines within catheters may cause temperature increase in surrounding regions. This heating problem has been investigated in several studies, with emphasis on properties such as resonance length and immersion length [1, 2, 3]. However, with the increasing development of MR-guided interventional systems, catheters are required to be connected to more complex connectivity systems, which transport the signal from the MR room to clinical monitoring tools. Few studies have recorded the effects of connecting catheters to standard clinical devices with unknown impedance (such as electrogram monitors, stimulator and electroanatomical mapping tools). The objective of this study was to investigate the effects of RF induced heating as a result of changing boundary conditions at the point of connection for a MR-guided clinical system.

Methods. Simulations were performed using a commercially available method-of-moments based EM field solver (FEKO, EM Software & Systems, Hampton, VA, USA). The electrode lines were modeled as electrical wires, which were then terminated with loads of different impedance. Experiments were performed on a GE 1.5 Signa scanner. To meet the general requirements of the ASTM F2182-02a standard for testing of MRI heating of implants [4], we built a human trunk simulator filled with a gelled solution (10g/L of polyacrylic acid - PAA, and 1.32 g/L of NaCl). The gelled phantom had final relative permittivity of 94 F/m and conductivity of 62 S/m. Temperature was recorded during pulse sequences with an average whole body SAR of 2.0W/Kg for 15 minutes. Finally, temperature measurements were performed using a fluoroptic system (Luxtron 3100, Luxtron, Santa Clara, CA). The catheters used [5] were not equipped with heat-mitigating devices.

Simulations & Results.

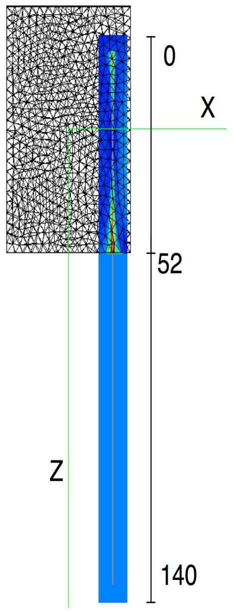

Fig. 1 Model of phantom and catheter geometry. SAR distribution is shown. The phantom center is aligned with the magnet isocenter. Catheter is placed tangential to E-field.

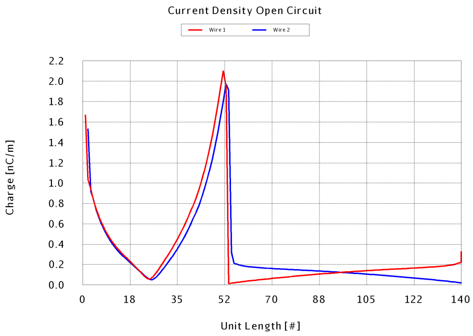

Fig. 2 Charge density plot of wire 1(from tip electrode) and wire 2 (from ring-electrode). Z_L=open case

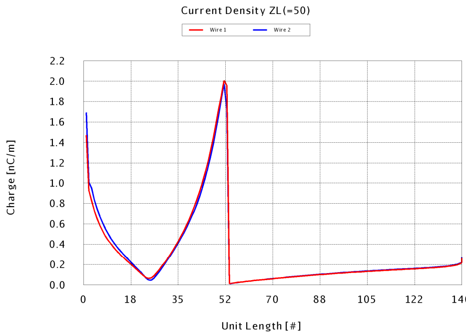

Fig. 3 Charge density plot of wire 1(from tip electrode) and wire 2 (from ring-electrode). Z_L=50 ohm case

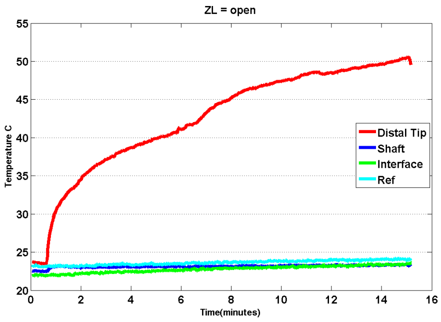

Fig. 4 Temperature measurements at probes located at the tip, along the shaft of the catheter, the gel-air interface and at a reference point away from the catheter. Z_L=open case

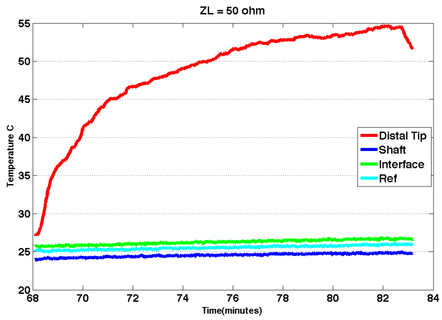

Fig. 5 As in Fig.4 the probes are placed in 4 locations and measurements are performed during 15 minutes RF application

In Figs. 2 to 5, simulations and experimental data are presented for several catheter termination cases: open case (catheter not connected) and for low to high impedance (Z_L) cases (only data for $Z_L=50\Omega$ is shown). In simulations, the catheter-tip (distal end) charge density increased about ~10% from open to loaded case. At the gel-air interface (insertion point) a ~2.1% increase was observed. In experimental measurements, tip temperature increase of ~9% was noted between Z_L=open and $Z_L=50\Omega$ (see Figs. 4 and 5).

Discussion. The overall results suggest that in MR-EP systems terminations may have a non-negligible effect on RF-induced temperature increase. In our setup the termination represents a change of impedance, an additional reflection point (in addition to the distal tip and entry point of the catheter); both simulation and experimental results show that this point alters significantly the current along the wire and the overall reflection coefficient. These preliminary results, which incorporate and confirm observations of previous studies [1, 2, 3], present new observations that may provide a more complete understanding of multiple-boundary configurations and help identify potential safety concerns relevant to real clinical applications.

Conclusions. The objective of this study was to investigate the effects of RF induced heating as a result of changing boundary conditions at the point of connection. A conclusion on heating characteristics of a particular device cannot be reached based only on measuring tip temperature of the fully or partially embedded device being imaged; however, such studies can lay the foundation for further studies to achieve higher standard of safety.

References. [1] JMRI 2000 vol. 12 (1) pp. 79-85; [2] 2000 vol. 43 (4) pp. 615-9 [3] PHYS MED BIO 2002 vol. 47 (16) pp. 2973-85; [4] ASTM F2182-02a, [5] Prototype provided by Imricor Medical Systems (Burnsville, MN, USA)