Insulation, lead-length, and sample-size affect the MRI-safety of implanted leads

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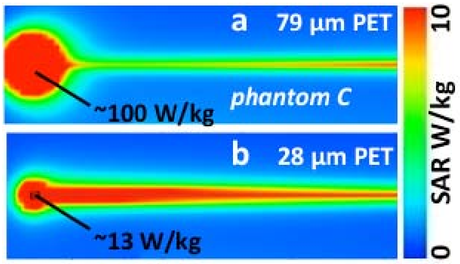

Fig. 1: Computed 1-g SAR at electrode and distal 5cm of 68 cm leads with 79µm (a) and 28µm (b) PET insulation.

Introduction. There are over two million patients in the USA with implanted conducting leads connecting therapeutic and diagnostic electronic devices to electrodes. Because conducting leads are susceptible to induced RF voltages and heating, their presence is a contraindication for MRI, denying such patients MRI's potentially life-saving benefits. Implanted leads are insulated and their effective lengths vary with patient size and lead function. Therefore we investigated lead heating and local specific absorption rates (SAR) in phantoms both theoretically, using numerical electromagnetic (EM) methods, and experimentally, with fiber-optic temperature sensors, as a function of sample size, lead length, and insulation thickness at 64 MHz (1.5T).

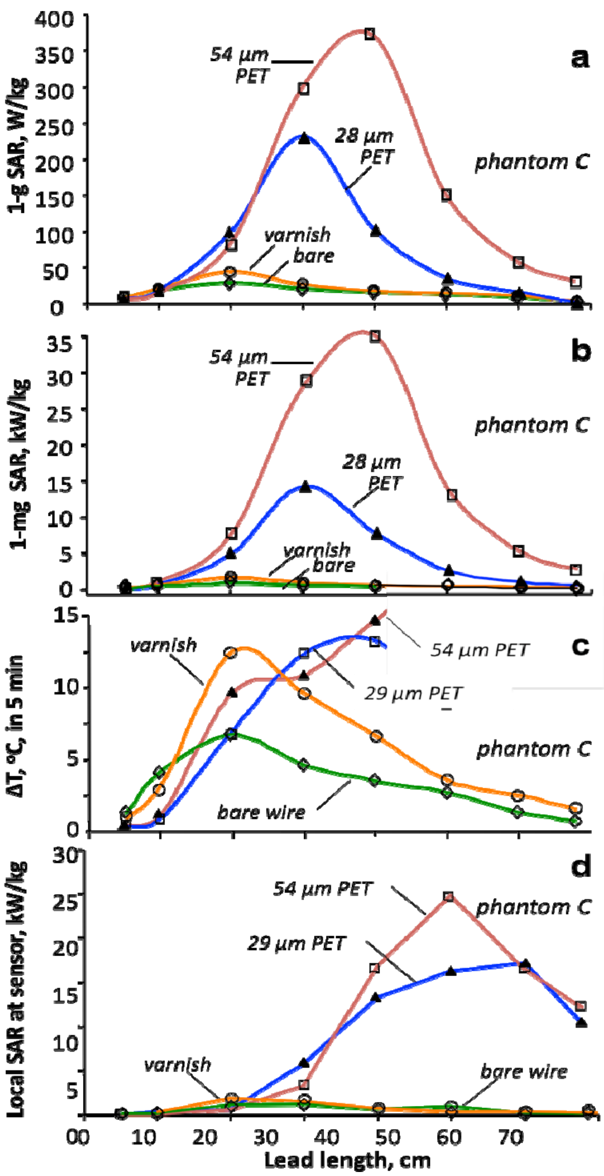

Fig 2: Computed 1-g (a) and 1-mg (b) SAR at electrode vs lead-length & insulation thickness. Experimental ΔT at 5min (c) & 1 inferred local SAR at electrode.

Methods. Leads were made of 0.18mm diameter Cu wire in 8 lengths from 5-75cm, and terminated with a 1.3mm long x 1.3mm diameter Pt-Ir electrode. Leads insulated with biocompatible 28-79 µm thick layers of polyethylene terephthalate (PET; dielectric constant, ε =3), or 3µm varnish, or no insulation, were inserted parallel to B_0, about 1cm from the edge of 3 different-sized polyacrylamide saline-gel phantoms (ε=80; conductivity 0.6 or 0.8 S/m). Two were18-cm cylindrical phantoms of length 30 and 45 cm. The third was a 74x20x10cm^3 rectangular phantom. These were positioned off-center in the MRI magnet with leads closest to the bore. Leads were fitted with *FISO* (Quebec, Canada) fiber-optic temperature sensors. A reference sensor was used to provide a scanner-independent SAR measurement based on the short-term (Δt) temperature change (ΔT) via:

$$SAR = c.\Delta T/\Delta t \quad [1] \quad \text{with } c = 4180 J/Kg°C.$$

Experiments were performed in a 1.5T GE MRI scanner with a high SAR MRI sequence. Data were normalized to 4W/kg local SAR based on the reference sensor reading and Eq. [1].

Theoretical SAR was computed using EM method-of-moments with Surface Equivalence Principle (*FEKO, EM Software* South Africa) applied to the above models loaded in a body coil producing a 4W/kg SAR at the edge of the phantom away from the lead.

Results. Both experiment and theory showed: (i) maximum heating occurs at the electrode (Fig. 1), and (ii) highest heating occurs in the largest phantoms. Extending the lead length beyond the phantom neither increased nor decreased SAR at the electrode vs. leads truncated at the phantom edge. Counter-intuitively, local SAR at the electrode increased as insulation thickness increased (Figs. 1-2): bare wire heated the least. SAR and lead heating didn't increase monotonically with lead length, but peaked for 25-60 cm leads, declining for longer leads. Experiments were hampered by gel phase changes for $\Delta T \geq 10°C$ (Fig. 2c), but the initial ΔT was used with Eq. [1] to determine SAR in the local volume sampled by the thermal sensors. This revealed extreme point SAR values of up to 25 kW/kg (Fig. 2d), which only approximated theoretical SAR by reducing computed volume averages to 1-mg (1x1x1mm; Fig. 2b).

Conclusion. Lead insulation thickness and lead length are key factors affecting the heating of uninsulated attached electrodes. SAR is highly nonuniform near the leads, so volume-averaged theoretical SAR doesn't match temperature measures unless the thermal sensor's sample volume is accounted for.