Resistance and Inductance Based MRI-safe Implantable Lead Strategies

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Introduction. Over a million therapeutic and diagnostic electronic devices–pacemakers, defibrillators, etc–are implanted in patients annually. Implants commonly include conducting leads connecting an active electronic device, to one or more electrodes for therapy/monitoring some distance away. Because conducting leads are susceptible to induced RF voltages and heating during MRI–which can damage devices and cause injury at the electrode–the presence of implants has long denied such patients the benefits of MRI. RF filtering on lead inputs can protect active devices, but does not stop induced voltages coupling to unprotected leads and electrodes.

The goal here is to develop implantable lead designs that could eliminate or reduce the hazards of MRI to such patients in future. Two impedance-based MRI-safe lead strategies are investigated experimentally and theoretically using numerical electromagnetic (EM) methods. We compare resistive and inductive leads to straight wire reference leads using a peak 1g applied specific absorption rate (SAR) of 4W/kg at 1.5T.

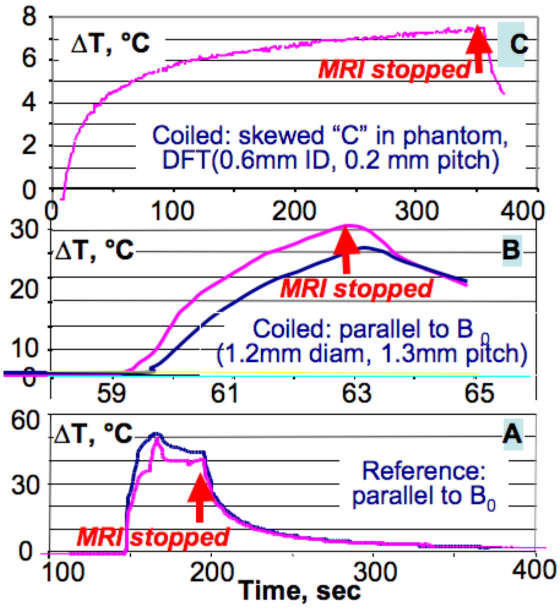

Fig. 1: ΔT vs time on electrodes of (A) ref. (B) coiled loose pitch, and (C) tight pitch leads.

Methods. Straight wire reference leads are made using 0.18mm diameter Cu wire with 0.025mm polymer insulation in 7 lengths from 5cm to 75cm. Inductive leads are wound from the same wire to form 1.2mm diameter chokes with lengths from 20-75cm. Test leads are also wound with coils of diameter 0.6-1.3mm, pitches from 0.2-1.3mm, multiple discrete coiled sections, and with Ag-core DFT wire, an industry standard. Five ~75cm resistive leads are formed by distributing ten 50-300Ω discrete on the same wire to obtain leads with total resistances, *R*, of 500-3000Ω. All leads end with a 1.3mm long x 1.3mm diameter terminal electrode.

Leads are inserted coaxial with B_0 into a 45cm long, 10-15mm from the edge of an18cm diameter polyacrylamide tissue-equivalent saline gel phantom (conductivity 0.8 S/m, dielectric constant 80) positioned 18cm off the magnet's iso-center. Leads are instrumented with *FISO* (Quebec, Canada) fiber-optic temperature sensors. Reference sensors at the edge of the phantom provide scanner-independent SAR based on the short-term (Δt) temperature change (ΔT): $SAR = c.\Delta T/\Delta t$ with $c = 4180 J/Kg°C$. Promising leads with minimal heating are re-tested in a skewed orientation relative to B_0.

Experiments are performed in a 1.5T GE MRI scanner with an MRI sequence adjusted to produce a 4W/kg local SAR at the reference probes for 5 min. Theoretical SAR is computed using EM method-of-moments and finite element methods (*FEKO, EM Software* (South Africa) applied to the model wires and phantom loaded in a body coil set to produce a 4W/kg SAR at the edge of the phantom away from the lead.

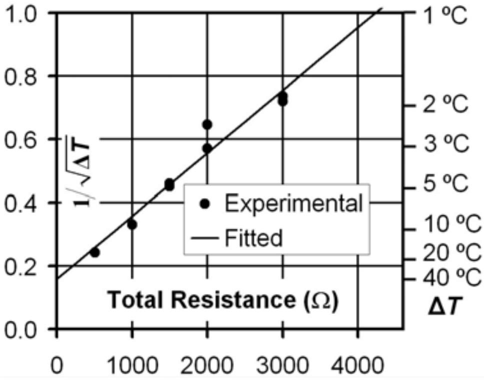

Fig 2: ΔT vs total lead resistance, R (Ω)

Results. Only short reference wires ≤10cm long heated <2°C. 20cm leads heat ~20°C. Full length ~75 cm leads heated >45°C in 15s at which point experiments were stopped due to gel break-down (Fig. 1A).

Resistive leads heated as $\sim 1/R^2$, as shown in Fig. 2. These data show that an *R* ≥3kΩ is required to limit ΔT to ≤2°C. Heating of inductive leads decreased as coil diameter increased and pitch decreased, consistent with increasing lead impedance. For the 1.2mm diam. coiled lead with 1.3mm pitch, ΔT>25°C (Fig. 1B). Reducing pitch to 0.2mm in a 0.6m DFT lead, succeeded in reducing ΔT<2°C when tested in an axial configuration, but this same lead heated ΔT>7°C when the lead was skewed (Fig. 1C). The EM analysis of SAR in a reference and a 0.6m coiled lead is shown in Fig. 3.

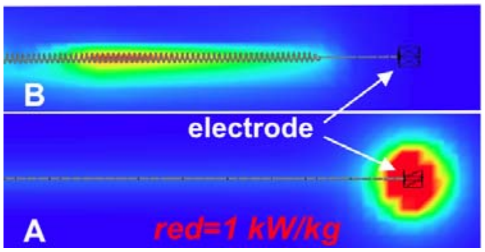

Fig. 3: Peak computed SAR for (A)ref. and (B)coiled (0.5mm ID/0.5 mm pitch) leads.

Discussion. These studies suggest that unprotected implanted leads ≥10cm long may heat >2°C during 1.5T MRI at 4W/kg, and suggest the importance of testing leads in multiple orientations. Resistive and inductance-based strategies can reduce temperature rise on 0.6-0.8m leads during MRI without requiring tuning to the MRI frequency, However, other factors affecting lead function and size when implanted–resistive loss, lead diameter and pitch when multiple conductors are coiled–are also key considerations.