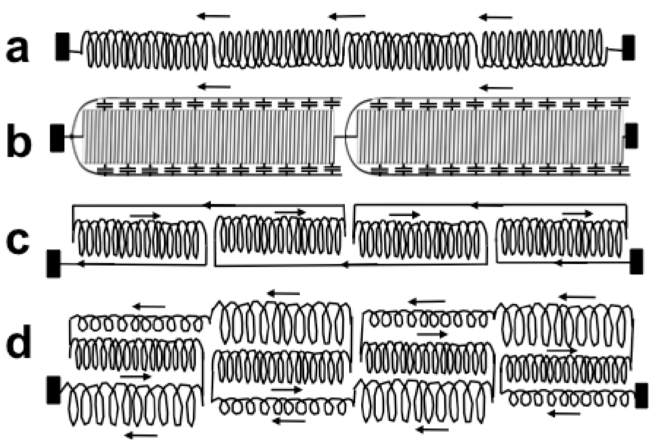

Fig. 1: (a)Continuously coiled, (b) RF trap; (c) single coil billabong; and (d) triple-coil billabong leads studied.

Towards MRI-safe implanted leads: a comparative evaluation of four designs

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Introduction. The presence of implanted conducting leads and therapeutic devices routinely denies millions of patients the potential benefits of MRI because of concerns about excessive induced RF voltages and the heating of leads and adjacent tissues during MRI. Our goal here is to develop and compare the MRI safety of implantable lead designs that will minimize these hazards for patients with implants in future.

We have investigated lead heating during exposure to 1.5T MRI at 4 W/kg specific absorption rate (SAR) of four passive lead designs that conduct low-frequency physiological voltages, but impede RF induced voltages during MRI. These are: (a) leads continuously coiled (as chokes); (b) leads including a series of tuned high-impedance RF traps; (c) "billabong" leads with reversed sections wherein the current direction opposes that of the induced RF electric field; (d) billabong leads with all sections coiled (Fig. 1).

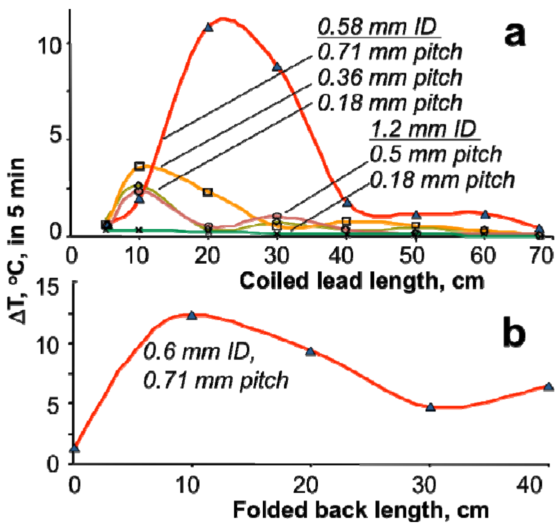

Fig 2: Coiled leads. (a)Temperature change, ΔT°C at electrode vs lead-length, coil pitch & diameter. (b) ΔT°C for the 68cm lead from (a) folded back on itself.

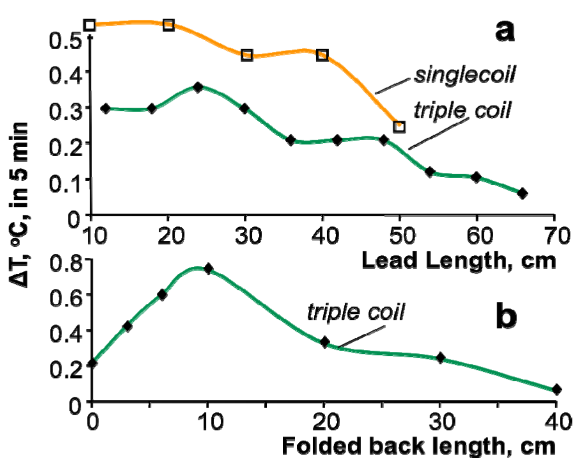

Fig 3: ΔT°C for single & triple coil billabong leads straight (a), and with the 68cm lead folded back (b).

Methods. Leads were made of 0.18mm diameter Cu wire with 3μm varnish insulation, terminated with a bare 1.3x1.3mm diameter Pt-Ir electrode. Coiled leads were wound with inner diameters (ID) of 0.6-1.2 mm, and pitches of 0.2-0.7 mm. The RF trap design used Cu braid or foil shielding with a polymer dielectric and trap lengths of 10, 15 and 25 cm. Billabong leads had module lengths of 4.5 and 2.2 cm with 1.2mm ID ($<\lambda/4$). The triple coil windings (Fig. 1d) were co-wound with 0.5, 1.3, and 1.3 mm pitches, respectively. All leads were stabilized by encapsulation in a biocompatible 25 μm thick layers of polyethylene terephthalate heat-shrink tubing.

Leads were inserted parallel to B_0, about 1cm from the edge, in a 74x20x10cm^3 rectangular saline-gel phantom (ε=80; conductivity 0.6 S/m; comparable to the body) which was located off-center in the MRI magnet with the lead closest to the bore. Leads were fitted with *FISO* (Quebec, Canada) fiber-optic temperature sensors. A reference sensor measured the applied SAR from the initial (Δt) temperature change (ΔT): $SAR = c.\Delta T/\Delta t$, with $c = 4180 J/Kg°C$. Experiments were performed in a 1.5T GE MRI scanner with a high SAR MRI sequence, and results normalized to 4W/kg based on the reference sensor. Promising leads (ΔT<2°C) were then tested with the ends folded back by varying lengths.

Results. Maximum heating occurred at the electrodes, but candidate leads with ΔT<1 or 2°C could be found for each design. Of the coiled leads, those with smallest pitch and maximum diameter (for highest inductance/unit length) fared best (Fig. 2a), but heating increased in fold-back experiments on some longer leads (Fig 2b). The RF trap prototypes were less flexible: trap impedances ≥0.8kΩ limited ΔT to ≤2°C. Single and triple layer billabong leads exhibited ΔT<1°C in both straight and fold-back configurations (Fig. 3a,b), outperforming continuously coiled leads of the same dimensions.

Conclusion. It is possible to create passive MRI-safe lead designs based on coiled, RF trap or, billabong windings. Other factors affecting implanted lead performance–size, manufacturability, mechanical and electrical integrity, multiple conductor needs–are also important for selecting suitable lead designs.