Reduction of RF Heating of Interventional Cryoprobes using Chokes

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Introduction

In the presence of electrically conductive structures, such as implants, wires, or interventional devices, radio frequency fields used in MRI can cause significant heating of the surrounding tissue[1-2]. The magnitude of the heat depends on the device geometry, position within the patient, and position relative to the RF coil electric field. These effects have been well described for guidewires at 1.5T and higher [1-4]. The purpose of this work is to show resonant RF heating from a cryoablation device at 0.5T, to determine the safe & worst-case configurations, and to demonstrate the use of RF chokes to reduce the unwanted currents on the probe cable that lead to tissue heating.

Method

Experiments were performed on a 0.5T GE Signa SP MRI scanner. A 4-rung birdcage body coil was used for RF excitation. Cryoprobes were inserted through the abdomen (transverse to axis of coil, ie A/P direction), and the cable was connected to the cryo-machine (grounded) on the other end. Heating was tested with the cryoprobe tip immersed in a NaCl solution or tissue samples. Temperature was measured with a fiberoptic temperature sensor (Luxtron, CA) taped to tip of the cryoprobe, during imaging with a multi-slice FSE sequence (TR=300ms, ETL=4, 5 slices). Several experimental setup configurations were tested to demonstrate the degree of heating at different device orientations.

RF chokes (or traps) were built to test their use in blocking the induced current on the cable. The choke shortens the effective length of wire to avoid resonance. Coupling of the choke with the field around the wire depends on the radius of the choke, the number of windings, the resonance frequency, Q factor & bandwidth of the choke. To achieve the highest possible reactance, a phenolic core toroidal inductance was wound with the maximum windings possible using a thin 28G or 24G wire. A phenolic core toroid was used for the convenience of sliding the choke over the cryoprobe cable without modifying the cable. It was tuned using a small parallel capacitance to resonate at Larmor frequency. Heating around the device was tested with various choke configurations: different toroid sizes (inner dia=7.7 & 9.4mm), different choke positions along the length of the cable, and using multiple chokes at different positions.

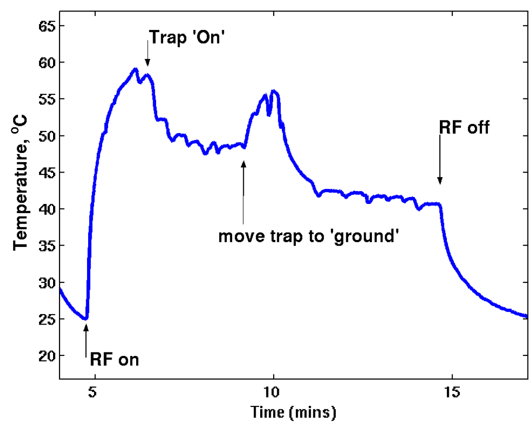

Figure1 : Heating of cryoprobe tip observed with birdcage RF coil transmit. Temperature increases about 30C during RF excitation. A 10^{o}C decrease is achieved by putting a choke on the cable.

Results

1. Increased RF power led to higher temperatures. No heating was observed if the RF power was turned off. No heating was observed with a low RF power GRE sequence. Scanning with and without gradients produced identical heating.

2. Heating was concentrated near the tip of the probe inserted into the tissue/saline solution. The cryoprobe cable acts an antenna, and the power deposition is concentrated at the tip, hence localized heating is observed there.

3. Heating had a strong dependence on the orientation and position of the cryoprobe cable. Placement close to coil rungs and end-ring capacitors produced more heating as the probe coupled with high local E fields there. Heating was less if the cable did not touch the body coil. Cable placement at the center of the coil, parallel to its longitudinal axis (ie along z-direction) resulted in very little heating, but this is unrealistic as this is where the patient would normally be. With the cable close to the coil rungs, orientation of the cable parallel to the coil rungs produced more heating than if cable was transverse to the rungs.

Large variations in temperature rise were observed when repeating the experiments. This is probably due to the complex interaction of the resonant coupling with the experimental setup, including the cable position, orientation, bending, and length of probe immersed in saline. All above observations agree with those reported in literature [1-4].

Heating was lowered with the RF choke on the cable, as shown in Figure 1. The smallest radius toroid that fit around cable was most effective at reducing the heating. The smaller gap between the conductive wire and the choke windings allowed better coupling with the field around wire, providing a more effective block for the induced RF currents on the wire. The reduction in heating observed depended on the position of the choke relative to the probe tip. A 'sweet spot' was observed at ~50cm from tip of probe inserted into tissue/saline, at which the choke was most effective in limiting the temperature rise. In some cases, using 2 or 3 chokes at different positions on the cable provided slightly better results than a single choke. However they did not do better than a single choke at the 'sweet spot'.

Discussion

At 2.8 m, the cryoprobe cable length was 0.2 λ_{air}. Nevertheless, the cryo-cable can effectively couple to the RF field and produce unwanted tissue heating. The choke shifts the local field concentration from the tip of the cryoprobe to the area around the choke. Since the choke is far from the subject, an intense field or temperature rise at that location may be tolerable. However, the trap windings can get hot, and in one instance arcing was also observed. The insulating sheath on the cryoprobe cable partly limits the coupling between the choke and the field induced on the conductive wire. Improving the coupling could allow a more effective reduction of the RF heating.

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