Use of saline coolant and alumina to facilitate heat transfer from conductive wires in interventional MRI

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INTRODUCTION:

An endovascular catheter tip can be steered in an MR scanner by applying current to microcoils wound at the catheter tip (1, 2). Nonferromagnetic conducting wires used in catheter tracking coils, intravascular imaging coils, guidewires, and braided catheters, however, have been shown to cause significant heating as a result of radiofrequency (RF) heating due to the antenna effect (3, 4). In addition to potential RF heating, current applied to microcoils for catheter tip steering can also cause resistive heating, resulting in significant temperature increases (5). The purpose of this study is to investigate the use of alumina at the catheter tip to facilitate heat transfer to saline coolant flowing in the catheter lumen to mitigate temperature increases produced by steering microcoil heating after application of currents necessary for deflection.

MATERIALS AND METHODS:

Three-axis microcoils of 0.002” wire were fabricated using a Laser Lathe process onto either Kapton polyimide film (DuPont, Wilmington, DE, USA) or alumina, and glued to the tips of 2.3 to 3 Fr microcatheters (Tracker-18-103101, 18-103102, and Renegade-18-253, all from Boston Scientific, Natick, MA, USA). Each microcoil was soldered to 0.005” wires running the length of the catheter, and connected a DC power supply (3 in total). In vitro testing was performed in a 1.5-T/64-MHz short-bore Intera MR imager (Philips Medical Systems, Best, The Netherlands) using a saline filled polyethylene vessel phantom (2 cm inner diameter, 100 cm length) within a transmit/receive body RF coil, and a balanced fast field echo pulse sequence (TR = 5.5 ms, TE = 1.6 ms, flip angle = 30º, 128 x 128 matrix, 5-6 mm slice thickness). A fluoroptic thermometry system (Luxtron, Santa Clara, CA, USA) was used to record the temperature of the microcoils. The thermocouple-microcoil-catheter-wire construct was secured and thermally insulated using heat shrink tubing (Raychem, North Spring, TX, USA). RF heating was measured at magnet isocenter. Resistive heating was measured after application of currents previously shown to cause significant catheter tip deflections (approximately 1W). Testing was performed in a worst-case scenario without blood flow, and with saline flowing through the catheter lumen at 0.28 cc/s and 1 cc/s in the polyimide tip experiments, and 0.12 cc/s, 0.25cc/s, and 0.48 cc/s in the alumina tip experiments. A second thermocouple was placed 1 mm beyond the face of the tip to measure the temperature of the effluent.

RESULTS:

In the absence of applied current, RF heating reached a maximal temperature increase of 1.8ºC after 70 s of “real-time” MR imaging (Figure 1). After application of current necessary for catheter tip deflection, clinically significant resistive temperature increases were noted, as shown in Figure 2. Without saline flowing in the catheter lumen, the temperature of the microcoils rose at a rate of 23˚C/W. With saline flowing through the catheter at a rate of 0.28 cc/s, the temperature rose less sharply at a rate of 13˚C/W, and still less sharply, 7.9˚C/W, with a saline flow rate of 1 cc/s. Using an alumina-tip catheter, the effluent temperature rise was further dampened, rising at 2.3˚C/W at a flow rate of 0.12 cc/s, and 1.2˚C/W at a flow rate of 0.48 cc/s, as shown in Figure 3.

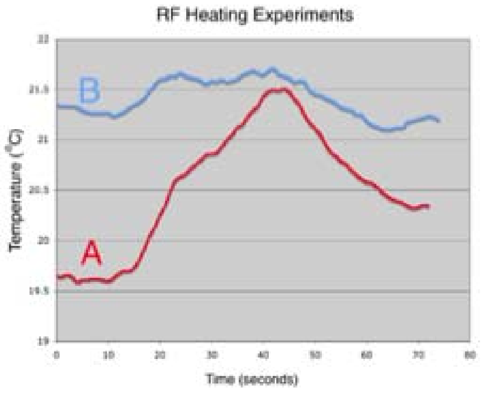

Figure 1. RF heating-induced temperature changes (at magnet iso-center). A. bFFE sequence active and single lead grounding. B. bFFE sequence active and lead ungrounded.

CONCLUSION:

Although RF-heating induced temperature increases were minimal, clinically significant temperature increase can result from resistive heating during application of current to steering microcoils. This study shows that resistive heating can be significantly dissipated by saline coolant flowing within the catheter lumen. Furthermore, the use of catheter materials with higher thermal conductivity such as alumina, can facilitate heat transfer to the saline coolant, resulting in further dampening of temperature rise. Even at the lowest flow rate, 0.12 cc/s, the highest temperature rise observed was 2.3°C/W. This is below the 2.4°C limit for local increase in the temperature of blood that causes coagulation, hemolysis, or vessel wall damage. The use of saline coolant and high heat conductivity material to facilitate heat transfer are feasible options not only for steering microcoils, but also for any microcoil-catheter design that uses nonferromagnetic conductive wires for imaging or tracking in interventional MRI.

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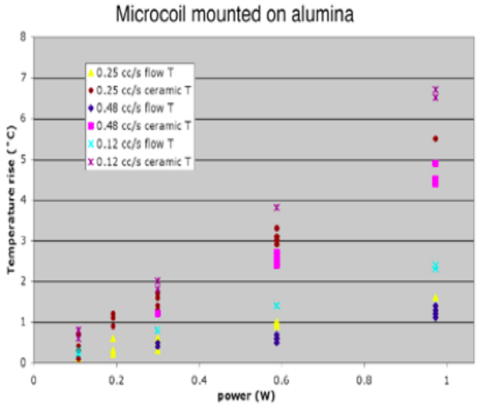

Figure 2. Resistive heating-induced temperature changes, in absence and presence of saline flowing through polyimide-tip catheter lumen.

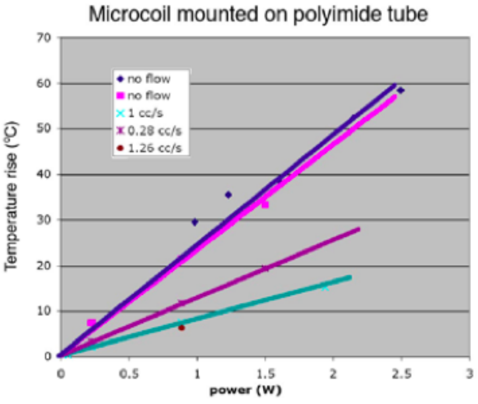

Figure 3. Resistive heating-induced temperature changes, in absence and presence of saline flowing through alumina-tip catheter lumen.