Unexpected Heating of MR-compatible Cyroablation Probes Using a Conventional 1.5T MR Scanner

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Introduction: Cryoablation therapy is frequently used for ablation of tumors in many organs in the body and palliative musculoskeletal therapy. Typically cryoablation is performed using CT or ultrasound guidance. Recently more of these procedures have been performed using MRI guidance. FDA-approved MR-compatible cryoprobes consist of hollow needles that pass cooled fluids that freeze tissue. Using two freeze-thaw cycles to at least -40°C, ice crystals are formed within cells and blood flow is interrupted leading to cell rupture, ischemia, and cell death. Many of these devices appear to have been developed for low field MRI prior to the development of high temporal and spatial resolution pulse sequences. Anecdotally, we had observed nerve stimulation and heating during animal studies using an FDA-approved system at 1.5T. In this study, we sought to determine whether heating of the cryoprobe in a clinically approved 1.5T MRI scanner may occur, which could be of concern during MR-guided tissue ablation.

Methods: A 24L rectangular agarose phantom approximating the size of the human torso was created and filled with 3g/L of agarose (Sigma-Aldrich) and 3.5 g/L salt to mimic the electrical properties of the human body.[1] The phantom was centered in a 1.5T clinical Siemens Espree MR scanner with the spinal array positioned beneath the phantom and two phased-array coils (body matrix) placed on top of the phantom to provide full MRI coverage as in a human torso study. Fiber optic temperature sensors (FISO, Inc, Quebec) were placed 3-5 cm from the edge of the phantom at off-axis locations simulating cryoprobe placement in the liver or kidney (Fig 1). One fiber optic sensor (#1 in Fig 1) was placed opposite the cryoprobe placement (#3 in Fig 1) as a reference. The thermal sensors were attached to a PC in the MR equipment room, which recorded the temperature change (ΔT) in real-time.

A typical three-plane scout scan (i.e., 2D gradient echo (GRE) 6 mm slice thickness (ST); 15 ms repetition time (TR); 7.15 ms echo time (TE); 40° flip angle (FA); 180 Hz/pixel bandwidth (BW); 35 cm field of view (FOV); and 256x180 image matrix) was applied for 10 min with only the fiber optic probes inserted to serve as a control. A real-time TrueFISP sequence (BEAT irTTT [2], 10 mm ST; 3.4 ms TR; 1.4 ms TE; 90° FA; 320 Hz/pixel BW; 30 cm FOV; and 128 x 128 image matrix), which is typically used for real-time interventional MR (iMRI), covering three scan planes was acquired for 10 minutes. Fiber optic sensors were taped to a cryoprobe (90 degree Icerod, Galil Medical Inc., Arden Hills, MN) close to the tip and handle and MRI was repeated during cryoprobe insertion into the phantom using the following MRI sequences: 1. three-plane scout: 2. BEAT irTTT; 3. standard cardiac SSFP cine (6 mm ST; 7.2 mm spacing; 3.8 ms TR; 1.63 ms TE; 930 Hz/pixel BW; 34 cm FOV; and 256x256 image matrix); and 4. temperature mapping sequence (TMap [3], GRE, 10 mm ST; 51 ms TR; 20 ms TE; 25° FA; 320 Hz/pixel BW; 30 cm FOV; and 128x123 image matrix). The peak temperature changes were calculated and compared to the reported acquisition SAR (acqSAR) in the DICOM headers.

Results: During scout MRI without the insertion of cryoprobes, there was no heating of the phantom (acqSAR=0.12). Using the real-time iMRI sequence, ΔT rose <0.5°C over 10 minutes (Fig 2). During cryoprobe insertion, large temperature spikes of10-15°C at the cryoprobe tip were observed with the iMRI sequence (Fig 3), with the highest values occurring during initial cryoprobe insertion (acqSAR=2.74). Large temperature swings were not consistently reproduced relative to cryoprobe orientation within the phantom or B_0. During cardiac cine MRI, no temperature spikes were observed. However, a monotonic increase of ΔT=1.1-1.3°C at the probe tip and ΔT=0.7°C at the probe handle occurred over 2 minutes with acqSAR=2.41 (Fig 4). No temperature spikes were observed during freeze or thaw cycles of the temperature probes when using the TMap temperature mapping sequence.

Discussion: Large temperature changes occurred during real-time MRI sequences, typically used for guiding probe insertion, in a human torso phantom. The increases were primarily on the cryoprobes themselves, which conduct to the phantom medium, consistent with electro-magnetic coupling between the scanner transmit coils and metallic probes. Heating of cryoprobes raises concerns because of the potential damage to normal tissues during image-guided probe placement in patients or inaccurate freezing during real-time MR thermometry. Thus, in clinical practice, it may be inadvisable to insert cryoprobes under real-time MRI-guidance in the scanner bore. In addition, during sterile procedures, the physician may not recognize heating due to poor conductance through gloves. The problem is not insolvable, but significant cryoprobe design changes are probably warranted.

References: 1. El-Sharkawy et al.. *Med Phys* 2008, **35:**1995-2006. 2. Pan et al. ISMRM 2011, p 9. 3. Flammang et al. ISMRM 2011 p. 1762.

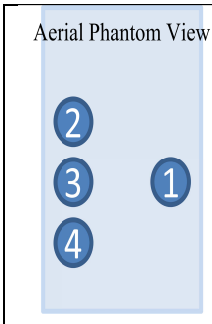

Fig 1: Schematic of placement of four fiber optic probes viewed from above the phantom.

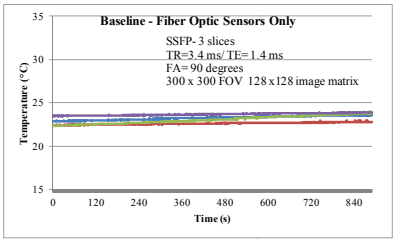

Fig 2: Using realtime iMRI (BEAT irTTT), minimal temperature changes were observed in the phantom without cyroprobes as expected.

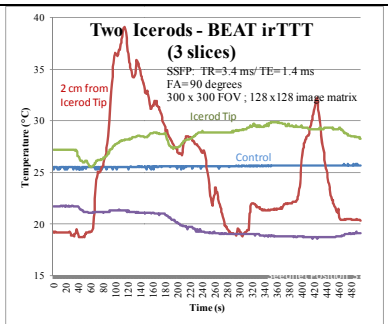

Fig 3: Large temperature spikes at the cyroprobe tip (red line) were observed during cryoprobe insertion using the iMRI pulse sequence (BEAT irTTT).

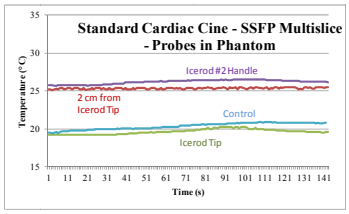

Fig 4: Local temperature increases of 1.1-1.3°C without temperature spikes occurred during cardiac cine MRI.