The Feasibility of Combined Magnetic Resonance Thermometry and Multiphysics Simulation to Evaluate RF Induced Heating of Metallic Devices

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Introduction: RF induced heating is an important safety concern as the number of patients implanted with medical devices increases and the use of 3T MRI becomes more prevalent. Prior to labeling devices as "MR Conditional," *in vitro* tests are performed using temperature probes to measure heating in the vicinity of the device during MRI[1]. Each probe can only measure temperature in a single location, setup and positioning can be difficult and inaccurate, and the standard *in vitro* test may not accurately reflect *in vivo* conditions[2]. Proton Resonance Frequency (PRF) shift thermometry is a well-established technique that can provide fast and accurate 3D maps of temperature change[3]. Similarly, multiphysics simulation solves for the oscillating electromagnetic field coupled with transient heat transfer, and can accurately characterize temperature changes in 3D[4]. We hypothesize that the combination of Magnetic Resonance Thermometry (MRT) and multiphysics simulation would provide a more accurate assessment of MR safety than current *in vitro* test methods, and could ultimately be used to evaluate RF induced heating of devices *in vivo*. The purpose of this work is to evaluate the feasibility of this approach by comparing temperature probe measurements with MRT and multiphysics simulation of RF induced heating near a metallic device using the standard *in vitro* MR safety test configuration.

Materials and Methods: Experiments were performed using a gradient echo, segmented echo planar sequence on a Siemens Tim Trio 3T MRI system (TR = 45.7ms, TE = 18.7ms, flip angle = 25°**,** voxel size = 2.1 x 2.1 x 5.0 mm). Four saturation pulses interleaved with the imaging excitation pulses were used to increase the average SAR to approximately 3W/kg. A 10 cm long, 1 mm diameter copper wire was positioned within the ASTM F2182-11a gel phantom (without the optional head portion)[1]. The copper wire was placed where the electric field is known to be high, on the left side of the phantom approximately 2 cm from the left edge and centered along the length and depth of the phantom. The gel consisted of distilled water, polyacrylic acid (PAA), sodium chloride (NaCl), and copper sulfate ($CuSO_4$). A fluoroptic temperature probe was used to measure the temperature at the tip of the copper wire while simultaneous RF induced heating and MRT were performed, resulting in 500 images/measurements acquired over approximately 360 seconds. This experimental procedure was repeated four times. The mean and standard deviation of the temperature probe and MRT measurements at the location of the probe were calculated separately. Additionally, a multiphysics simulation (COMSOL; Stockholm, Sweden) was developed to predict the temperature history of the copper wire during RF induced heating. Previous work has shown that the simulation is able to accurately solve for RF induced heating during MRI when the appropriate boundary conditions are considered[2,4]. Since the simulation does not rely on imaging, it can predict the temperature in the region of interest where the copper wire and temperature probes perturbed the MR signal.

Results: Figure 1 shows a comparison of the simulation and MRT temperature contours (sagittal slice) after 360 seconds of RF induced heating. Figure 2 shows the temperature versus time data for the temperature probe as well as MRT and simulation results from the same location. The standard deviation is plotted as error bars for the temperature probes and the MRT data.

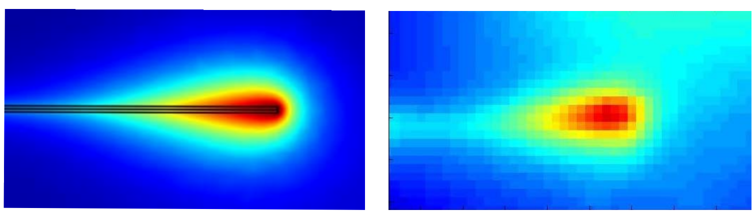

Figure 1. The temperature contour of the copper wire after 360 sec of RF induced heating using the simulation (left) and MRT (right).

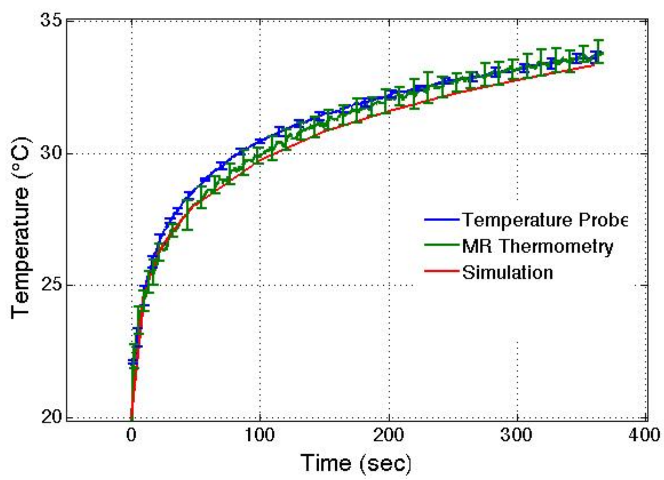

Figure 2. Temperature versus time for the average temperature probe data (n=4), the average MRT data (n=4) and the simulation. The error bars associated with the temperature probe and MRT represent +/- 1σ.

Conclusion: PRF shift thermometry provided a temperature map in the vicinity of a metallic device that closely agreed with direct temperature measurement. Furthermore, a multiphysics simulation accurately matched both the MRT and temperature probe results. The techniques are complementary in that MRT can provide temperature results that explicitly account for boundary conditions (e.g., vascular flow and perfusion) while simulation circumvents errors due to image artifacts. The results of this feasibility study indicate that an approach combining MRT with multiphysics simulation can provide an accurate, spatially resolved map of RF induced heating *in vitro*, and suggests the potential for evaluation of implanted medical devices *in vivo*. This could lead to more accurate and personalized assessment of the MR safety of medical devices, with the goal of ensuring that patients with "MR Unsafe" devices are precluded from MRI scans, and those with "MR Conditional" devices have access to clinically indicated MRI scans that may have otherwise been inappropriately withheld.

References:

[1] ASTM Standard F2182-11a, "Standard Test Method for Measurement of Radio Frequency Induced Heating On or Near Passive Implants During Magnetic Resonance Imaging," ASTM International, West Conshohocken, PA, 2011, DOI:10.1520/F2182-11A, www.astm.org.

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