Temperature Measurement Nearby an Iceball using the Proton Resonance Frequency method: Recalculation of Susceptibility Artifacts.

A. Kickhefel[1], R. Salomir[2,3], J. Roland[4], P. Gross[4], F. Schick[1], and C. R. Weiss[5]
[1]Eberhard-Karls-University Tübingen, Tübingen, Baden-Württemberg, Germany, [2]University Hospitals of Geneva, Switzerland, [3]University Hospitals of Geneva, [4]Siemens Healthcare, Erlangen, Germany, [5]Department of Radiology, The Johns Hopkins University School of Medicine, Baltimor, United States

Introduction. Minimally invasive treatments such as Laser-Induced Thermotherapy (LITT), Radiofrequency Ablation (RFA), High Intensity Focused Ultrasound (HIFU) and microwave ablation are commonly used in the clinical setting for the treatment of focal cancers throughout the body. Magnetic Resonance Imaging (MRI) based temperature monitoring is often performed in order to provide real-time feedback to the operating physician, typically using the Proton-Resonance-Frequency (PRF). Another commonly used minimally invasive local tumor therapy is cryo-ablation, which creates an ice ball to induce cell death. As for high temperature thermal therapies, it is often necessary to monitor temperature changes in real-time during a cryo-ablation procedure, particularly in at-risk structures adjacent to the target tissue/organ. Currently, temperature monitoring is performed using invasive temperature probes which must be placed by the operator, a time consuming and potentially dangerous procedure. Considerable research was made for non-invasively measuring the sub-zero temperatures within the ice-ball itself using MR [1], however, there has been little or no investigation into using MR to measure the near-zero temperatures which are induced around the ice-ball. As long as the tissue still contains liquid water, the PRF method should be applicable. However, the ice ball itself disturbs the local magnetic field because of susceptibility contrast with defrosted tissue, which strongly influences the PRF method.

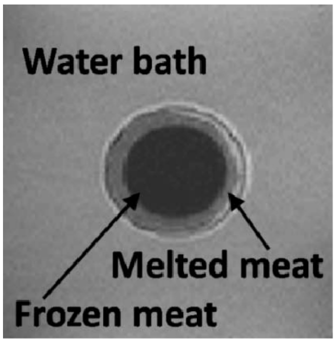

Figure 1: Experimental setup

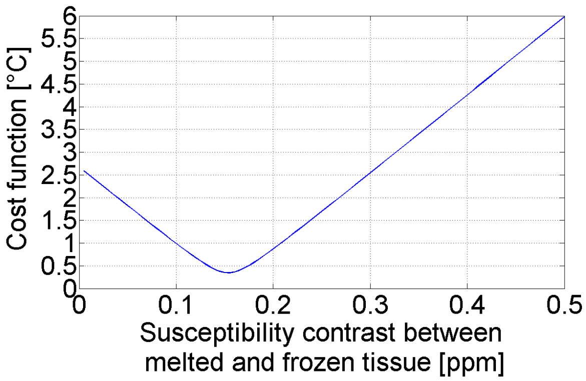

Figure 2: Correlation of cost function and explored susceptibility contrast between melted and frozen tissue. The cost function is the standard deviation of the spatial series of temperature along the ice ball border in the central slice

In this study we demonstrate that susceptibility artifacts in GRE phase image induced by ice ball can be corrected allowing the PRF method to be used to monitor the near zero temperature during cryoablation.

Material and Methods. The experimental setup is shown in figure 1. A sample of meat (pork) was frozen in a standard freezer to a temperature of ~ -4°C and defrosted within a 1.5T MR-system (Magnetom Avanto, Siemens Erlangen, Germany) using a warm water bath. During the defrosting, repetitive acquisitions were performed using the Gradient Echo sequence (GRE) (TR/TE/TA=800ms/40ms/57,83s, 12slices, slice thickness 2mm, FOV 300x300mm^2, matrix size 192x192, bandwidth 160Hz/Px, flip angle 60°). Susceptibility artifacts were then corrected in post-processing. First the susceptibility difference between frozen and melted meat was determined retrospectively. This value of susceptibility contrast ($\Delta\chi$) was explored iteratively by changing it from 0 to 0.5ppm with steps of 0.005 ppm searching for the minimum of a cost function. Note that $\Delta\chi$ is assigned to the segmented region where tissue state changed.

Cost function was defined as the standard deviation of the corrected temperature series (see equation below derived from ref.[2]), near the ice ball surface in the central slice. The assumption was the border of the ice ball must have the water physical state transition temperature, hence a uniform value. In the second step, this knowledge was used to finally correct the GRE phase data for susceptibility artifacts. This method used a convolution in the k-space with the following kernel, where α is the temperature PRF coefficient, $k_{x,y,z}$ the coordinates of the k-space and FT the Fourier Transformation.

$$\Delta T_{corr}(\vec{r})[°C] = \Delta T_{PRFS}(\vec{r})[°C] + \frac{1}{|\alpha|[ppm/°C]} \cdot FT^{-1}\left[\left(\frac{1}{3} - \frac{k_z^2}{k_x^2+k_y^2+k_z^2}\right) \cdot FT[\Delta\chi(\vec{r})[ppm]]\right]$$

Results. The susceptibility difference between melted and frozen tissue was found 0.155 ppm for a best-corrected temperature uncertainty of 0.34°C (Figure 2). Figure 3 shows a corrected and non corrected temperature image. Computing time was less than 1s in Matlab. Visible susceptibility artifacts induced temperature errors of ±6°C around the ice ball. These errors were fully corrected using our method (Figure 3). Within the ice ball no MR-signal is obtainable and these temperature values were set to zero.

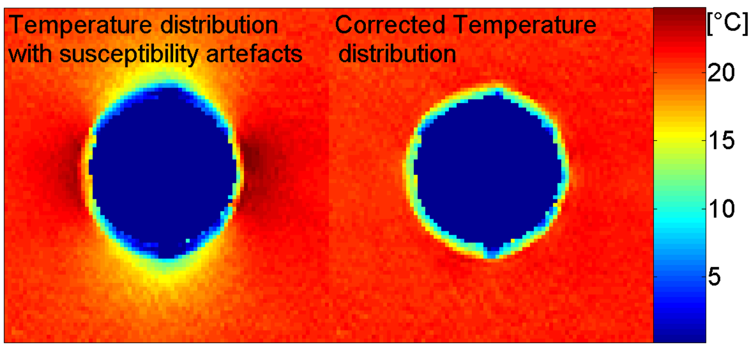

Figure 3: Comparison of temperature distribution with and without correction of the susceptibility artifact measured using the PRF method

Conclusion. This study demonstrates a method for correcting the peri-ice ball susceptibility artifacts induced by freezing tissue. Using an in-line post processing system, this method could be applied during clinical MR-guided cryotherapy, and allow for the non-invasive monitoring of near zero temperatures in at risk tissues adjacent to the target lesion.

References. [1] Josan S, Bouley DM, van den Bosch M, Daniel BL, Butts Pauly K. J Magn Reson Imaging. 2009 Jul;30(1):169-76.
[2] Salomir R, de Senneville BD, Moonen CTW. Concepts in Magnetic Resonance. 2003 (part B), vol 19B (1) 26-34