Robust MR Thermography with iZQCs

G. Galiana[1,2], R. T. Branca[2], E. R. Jenista[2], and W. S. Warren[2]
[1]Chemistry, Princeton University, Princeton, NJ, United States, [2]Chemistry, Duke University, Durham, NC, United States

Introduction

An accurate method for noninvasive temperature monitoring in vivo would be invaluable for hyperthermic cancer treatments[1]. These therapies selectively heat tumors with RF or microwave radiation, thereby bringing about enhanced drug delivery (up to 30-fold), inhibited cell repair, and even cell death[2]. Unfortunately, this promising treatment has been stymied because current methods to map temperature in vivo are inadequate. Conventional MR temperature maps are easily distorted, and provide only a relative measurement of the temperature. Instead we propose a different method based on the detection of water-fat iZQCs (intermolecular Zero Quantum Coherences) which produce an *absolute* temperature map and are insensitive to other distorting factors.

iZQC thermography, like conventional thermography, uses a phase image to determine the evolution frequency in each pixel, since the water resonance frequency shifts by 0.01ppm/ºC. In the conventional method, this frequency shift is often overshadowed by susceptibility gradients, field drift and other local factors. Instead, we use the phase image from an iZQC sequence to determine the evolution frequency of water-fat iZQCs. This frequency reflects (ω_{H2O}-ω_{fat}) between water-fat spin pairs that are about 100μm apart and see virtually the same local environment. Since the frequency of fat varies little with temperature but does vary with other local effects, nonthermal contributions to the signal (including inhomogeneous broadening) are suppressed. We have developed a modified pulse sequence to selectively detect the signal, and have demonstrated its potential for accurately measuring temperature.

Methods

To isolate the water-fat coherences, two novel filtering schemes were developed to dephase and then cancel all signals except those arising from inequivalent spin pairs. For example, a selective 180 pulse can cause a transition from zero to double quantum coherence only for iZQCs between inequivalent spin pairs; coherences between equivalent spins pairs (such as H_2O-H_2O coherences which are typically dominant) are unaffected, and are dephased by a double quantum gradient filter. We have also employed tailored pulses which constructively amplify signal from water-fat ZQCs, but cause iZQCs between like spin pairs to cancel. In addition, the method acquires two different types of ZQCs in each scan so that the detected evolution is even more resilient to motion effects.

Results and Discussion

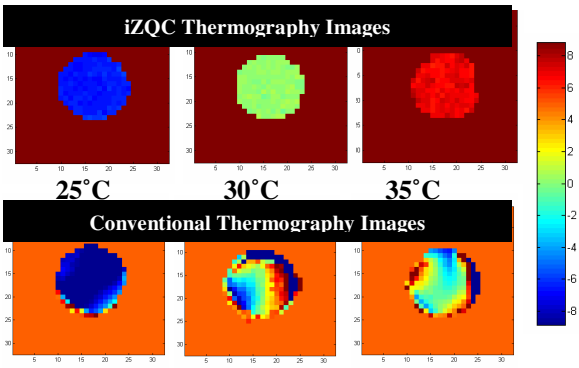

Figure 1: Temperature maps calculated from iZQC images (above) accurately reflect the uniform temperature of the sample, while conventional images (below) are distorted by magnetic field inhomogeneity.

Figure 1 illustrates the advantages of iZQC thermography with a water/fat phantom (heavy whipping cream) at three uniform temperatures. The iZQC image, at top, accurately reflects frequency shifts from temperature and is not distorted by other factors. In contrast, the standard imaging method shows a wide range of proton frequency shifts which cannot reasonably be attributed to temperature variations. Since the phantom was maintained at uniform temperature using a thermoprobe controlled heater, the wide range of frequencies detected in the conventional image most likely reflect magnetic field inhomogeneities and not temperature. The method has also been demonstrated post-mortem in an (OB-M) obese mouse model. (Figure 2) These results demonstrate the potential of iZQC thermography to accurately guide hyperthermic cancer treatments.

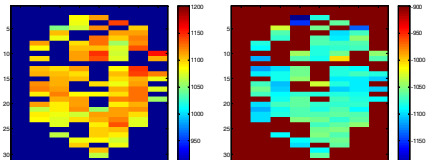

Figure 2: Frequency maps calculated from the two types of ZQCs in a post-mortem OB-M mouse model

References

[1] Dewhirst, M. et al, Int. J. Hyperthermia, 21(8), 779-790. (2005)
[2] Prosnitz L.R. and M.W. Dewhirst, Int'l J. Rad. Onc. Bio. Phys., 33, 963-964 (1995).
[2] Vathyam, S. et al, Science, 272, 92. (1996)
[3] Warren, W.S. et al, Science, 262, 2005. (1993)