Absolute Temperature Measurement of QC Diffusion Phantoms via Low Bandwidth EPI

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Introduction

Diffusion phantoms are required for QA/QC in multicenter trials. Ice water phantoms control temperature [1], but the range of diffusion coefficients in ~0°C media is limited. To achieve quantitative values at ambient temperatures, better than 1°C precision of internal temperature readout of the phantom is desired. MR-thermometry based on PRF shift of water resonance [2] is widely used to track temperature with limited sensitivity. Tm-DOTA/DOTMA solutions greatly enhance temperature sensitivity [3], but require tuning proton frequency over an extended range (~120PPM) which presents a challenge on some clinical systems. In this work, sensitivity of PRF to estimate absolute temperature is improved via a low bandwidth (LBW) EPI applied to a long T2, temperature-sensitive material.

Methods

An aqueous tert-butanol solution provides a doublet of long T2 (>250ms) peaks separated by 3.54PPM at room temperature. Long T2 permits use of low phase-encode bandwidth (3.7Hz/acquired pixel) SS EPI sequences thereby improving sensitivity of chemical shift detection between water and methyl resonances by separation along the phase-encode direction. A 20mm sphere of tert-butanol solution was encased in a 38mm sphere of D2O to create two widely separated targets surrounded by signal-free zones, where apparent separation distance inversely scales with temperature. A MatLab script determined spatial separation of water and methyl resonances via >6-fold interpolation and sub-image 2D cross-correlation. The LBW EPI-based tert-butanol probe was calibrated in a variable-temperature water bath with simultaneous temperature recording via fiber-optic probe at the center of the tert-butanol sphere. The calibrated probe was subsequently utilized for independent *in situ* MR thermometry of a DWI phantom containing 0,20,30,40,50% polyvinylpyrrolidone (PVP) solutions for a range (0.3 to 2.3x10^{-3}mm^2/s) of diffusion coefficients [4]. Key acquisition settings include: 3T scanner; torso coil; TR=4000; TE=273; AcqMatrix=256x253; Slice=2mm; FOV=330mm; geometric correction="no". The PVP diffusion phantom was scanned with a standard DW EPI sequence at b=0, 500, 1000.

Results

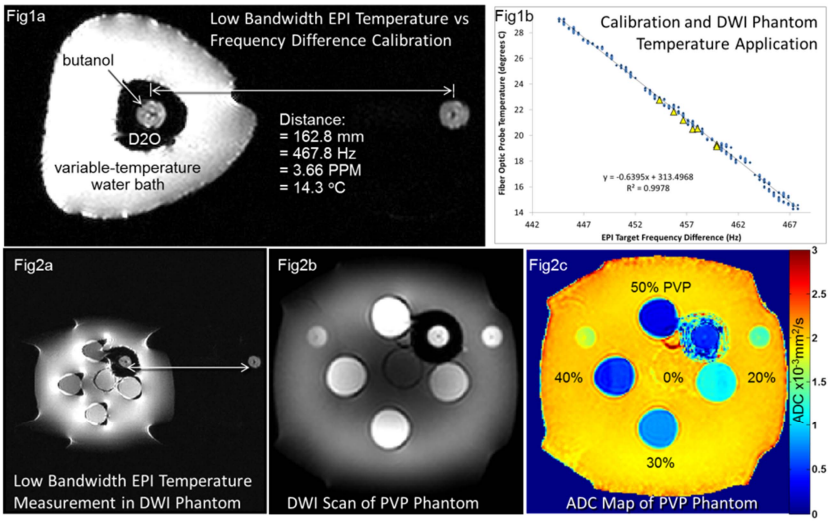

Fig1a illustrates a LBW EPI used for calibration where target separation distance reports on chemical shift (and temperature). Since both resonances occupy the same physical space, influence of distortion due to local shim and spectrometer drift did not influence detection of separation with sub-pixel precision. Disabling geometric correction ensured water and methyl targets were not differentially shifted based on apparent location. Resultant separation distance vs temperature calibration plot is shown by dark "♦" symbols and regression line in Fig1b. Data from LBW EPI readout of the tert-butanol probe incorporated in a PVP DWI phantom measured independently at several temperatures are shown as yellow "▲" symbols in Fig1b. RMSE of MR-thermometry values derived from regression relative to coincident fiber optic probe measurement was <0.3°C. This error is consistent with spread in calibration points off the regression line. Error propagation analysis predicts a temperature calibration uncertainty of ~1°C. Fig2a shows the LBW EPI of a butanol probe-equipped DWI phantom. High bandwidth DWI_{b1000} and resultant ADC map are in Fig2b and c respectively.

Conclusion

Feasibility of automated *in situ* MR thermometry was successfully demonstrated for application in a DWI QC phantom. In the context of multicenter clinical trials, traditional single-voxel MRS PRF methods can be challenging for some centers. The proposed LBW EPI approach provided consistent internal phantom temperature measurement to an RMSE of 0.3°C and predictive model uncertainty of ~1°C. Most of the predicted uncertainty stems from the calibration step, thus reduced temperature uncertainly may be achieved via independent high resolution NMR calibration of the tert-butanol probe.

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References: [1] Malyarenko D, et.al. JMRI 2013;37(5):1238-1246. [2] Sprinkhuizen SM, et.al. MRM 2010;64(1):239-248. [3] Boss M, Proc ISMRM 2013; 4306. [4] Pierpaoli C, et.al. Proc ISMRM 2009; 1414.