Total Proton Resonance Frequency Shift Coefficient in the Porcine Brain to Image Radiofrequency Heating in Ultra-high Field MRI

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Introduction Total proton resonance frequency (PRF) shift coefficients are needed in the porcine brain to non-invasively measure radiofrequency heating with sub-degree C accuracy during head imaging in ultra-high fields. Total PRF shift coefficient depends on the changes in the molecular screening, volume susceptibility, and electromagnetic properties with temperature (1). Traditionally, the PRF shift coefficient of -0.01 ppm/^{0}C has been used for all tissue types, which is equal to the PRF shift coefficient due to the change in the molecular screening constant of water protons with temperature alone. However, the effect of the other components on the PRF shift coefficient may be significant since a wide range of the PRF shift coefficients has been reported in the literature; e.g., -0.0067 ppm/^{0}C for a canine brain, -0.0097 ppm/^{0}C for a porcine muscle, -0.0135 ppm/^{0}C for a porcine liver, -0.0146 ppm/^{0}C for a rat thigh, etc. (2-5). The PRF coefficient, to the first approximation, linearly changes with temperature due to the change in the local magnetic field. The local magnetic field changes with temperature due to the change in molecular arrangement and thus, molecular screening of the water proton; volume magnetic susceptibility; and the electromagnetic properties (3). Neglecting the effects of change in volume magnetic susceptibility and electromagnetic properties on the PRF shift coefficient may introduce significant errors in MR imaging based temperature measurements (6). The total PRF shift coefficients were measured in the porcine brain since pigs are regularly used as thermo-physiologically conservative models to humans (7).

Experiment design and Methods The brain was extracted from a freshly euthanized 54.8 kg pig. The brain was suspended in a 150 ml, water tight tube filled with 0.9% saline. The tube was taped to a plastic table and put in a cylindrical water bath such that the tube was placed at the center of the water bath. The temperature of the water bath was set to a desired value by running water through it. The temperature of the running water was changed using a temperature controller set outside the magnet room. The temperature in the bath was measured and controlled using a fluoroptic probe placed inside the water bath. The temperature of the water bath was set to the following values to obtain phase shifts and measure PRF shift coefficient: 35 ^{0}C, 37.2 ^{0}C, 38 ^{0}C, 39 ^{0}C, 40.8 ^{0}C, and 43.4 ^{0}C. Phase maps were obtained by using a gradient recalled echo sequence with the following parameters: Field strength = 3 T, TR = 60 ms, TE = 14.8 ms, Flip angle = 5 ^{0}, Resolution = 192X192, Field of view = 192 mm X 192 mm, Averages = 3, Slice thickness = 5 mm. The phase maps were obtained after the water bath and the porcine brain sample attained thermal equilibrium (i.e., ~ 1 hours after the temperature was set as verified by fluoroptic thermometry in earlier experiments). The phases were obtained by post-processing the raw data using matlab.

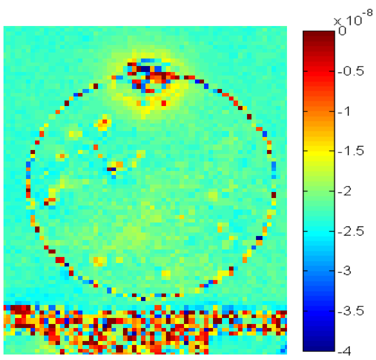

Figure 1 Total PRF shift coefficient map in the porcine brain in ppm/^{0}C.

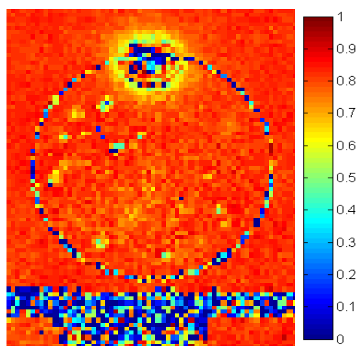

Figure 2 Correlation coefficient R^2 map in the porcine brain.

Results and Discussion Figures 1 and 2 present the map for the total PRF shift coefficient and the corresponding R^2 in the porcine brain. The average total PRF shift coefficient map in the porcine brain was measured as -0.02 ppm/^{0}C. The measured value is comparable to the total PRF shift coefficient value of -0.0192 ppm/^{0}C reported by Weis et al. (8) in the porcine brain in vivo. The measure coefficient is significantly different than the conventionally used value of -0.01 ppm/^{0}C. The significant difference between the two PRF shift coefficients suggests strong dependence of the variation in the volume susceptibility and electromagnetic properties with temperature on the total PRF shift coefficient. Future investigations are desired to better understand the possibly tissue-dependent contribution of the volume susceptibility and electromagnetic properties on the total PRF shift coefficient to non-invasively measure accurate in vivo temperatures at ultra-high fields.

Summary The average total PRF shift coefficient in the porcine brain was measured as -0.02 ppm/^{0}C. Future investigations are needed to better understand the contribution of the volume susceptibility and electromagnetic properties on the total PRF shift coefficient of various tissues.

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