Quantitative Pulsed CEST

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Introduction: Chemical exchange saturation transfer (CEST) is a magnetic resonance imaging method whereby the properties of exchangeable protons, including concentration [1]and exchange rate, can be probed. This measurement of hydrogen exchange with solvent water can further yield the average pH [2] or temperature [3] of the environment; factors which can aid in the detection of cancer [1] or in assessing stroke severity[4]. Conventionally, CEST experiments have been conducted using a long (several seconds) saturation pulse, which allows a continuous wave (CW) interpretation of the steady state magnetization and maximizes the available CEST-related contrast[5]. This poses a problem for clinical development, however, given hardware restrictions on maximum pulse length and limits on allowed levels of human radio-frequency absorption. We have bypassed these restrictions by developing a method of pulsed CEST which permits a short saturation pulse, but which imposes a new steady state condition. By developing a model which incorporates relaxation parameters as well as those imposed by the pulse sequence, we are able to quantitatively determine the properties of the CEST component.

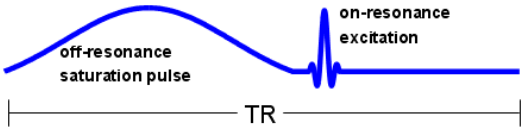

Figure 1: *Pattern of RF excitation for the pulsed CEST sequence. Acquisition occurs after each on-resonance excitation pulse.*

Method: A phantom consisting of 1M ammonium chloride was prepared in 10 mM citric acid buffer at pH 5. MR imaging was performed on a GE Signa 3T scanner using the stock spoiled, gradient-recalled sequence with the addition of magnetization transfer and modified to include a custom saturation pulse [6] (see Fig. 1). Imaging parameters were as follows: saturation pulse width/TR/TE = 106/200/5 ms, saturation pulse flip angles = 818º, 1023º, 1227º, and 1636º. Spectra were acquired by ranging the frequency of the off-resonance saturation pulse from -800 to 800 Hz. Corrections were made for B1 inhomogeneity and errors in center frequency. The T1 of the phantom was measured separately by a standard inversion recovery experiment. Experimental data was fitted to a two-pool compartmental model of the Bloch equations including exchange and pulsed off resonance excitation modeled by a piecewise constant approximation[7].

Results and Conclusions: Figure 2 and 3 show the observed signal and the corresponding fit for the ammonium chloride sample as a function of the frequency of the off-resonance saturation pulse. Data was adjusted to account for an 11Hz error in center frequency, and 13.4% error in the B1 field. The outcome of the fit was as follows: exchange rate = 303 Hz, T2 of CEST pool = 46ms, magnetization associated with the CEST pool relative to bulk water = 4.5%. The error in the parameter estimates from the fitting procedure was less than 3%. This experiment has demonstrated the feasibility of pulsed CEST imaging on a clinical scanner, and the ability to derive quantitative results.

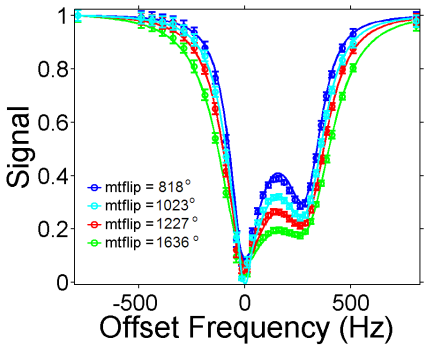

Figure 2: *Fitted CEST spectra for 1M ammonium chloride phantom, with spectra acquired at 4 different RF saturation powers, resulting in flip angles of* 818º, 1023º, 1227º, and 1636º *.*

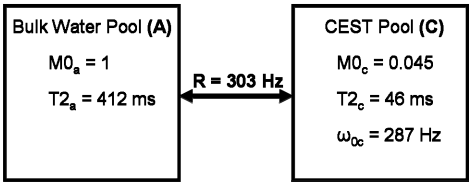

Figure 3: *Results of the fit to the two-pool compartmental model for the CEST spectra in 1M ammonium chloride. The model fits for $T2_a$ ($T2$ relaxation for the bulk water pool), $M0_c$ (size of the CEST pool relative to bulk water), $T2_c$ ($T2$ relaxation of CEST pool), and ω_{0c} (resonance frequency of the CEST pool).*

References:

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