MRI Phantoms with Independently-Controllable Biexponential-T2 Decays

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Introduction:

Magnetic Resonance Imaging phantoms are useful for both pulse sequence development and routine quality control. Most phantoms are comprised of a contrast agent-doped water or gelatin mixture, with contrast agent concentration adjusted to create T_1 and T_2 relaxation times that are reflective of a particular tissue. However, relaxation in some tissues cannot be described well by a simple mono-exponential relaxation term, and evaluating certain pulse sequences may require a phantom that exhibits multi-exponential relaxation. To this end, Jones et al proposed the use of dairy cream phantoms, which rely on differing relaxation characteristics of water and fat to generate bi-exponential relaxation [1]. Dairy cream has the benefit of being widely available and coming prepared with reliable fat concentration, but also has the drawbacks of having a short shelf life, a finite number of available fat concentrations, and a relatively large water-fat chemical shift difference. Lee et al. used an aqueous solution of urea as a phantom of two exchanging pools [2], which is explored in this work as the basis for a MRI phantom with bi-exponential relaxation.

Methods:

A series of urea-water and urea-water-agar mixtures were prepared with varying concentrations of urea (and agar) and adjusted to a pH of 9.1 by HCl titration. At this pH, the urea-water mixtures contain two chemically-unique pools of protons—urea is ~1ppm chemically shifted downfield from water. To these mixtures, varying concentrations of $MnCl_2$ and/or 50-nm iron oxide nanoparticles (Nanomag®-SPIO-D, Micromod Partikeltechnologie GmbH) were added to contribute primarily inner-sphere and outer-sphere relaxation agents, respectively. T_2 relaxation characteristics were then measured at 300 MHz using a CPMG pulse sequence on a 7T 16 cm horizontal magnet. For each sample, 4000 echoes were collected at 1 ms echo spacing, with a 15 second TR. Even echo magnitudes were then fitted with a broad range of decaying exponential functions in a non-negative least squares sense, subject to a minimum energy constraint, producing a so-called T_2-spectrum. From each spectral component was computed the geometric mean T2 and the fractional signal contribution.

Results and Discussion:

In absence of either contrast agent, aqueous urea and water protons exhibited T2's of ~60 ms and ~1000 ms respectively. Inner-sphere contrast agent doping (Fig. 1) yielded $MnCl_2$ relaxivities of 0.177 and 0.030 $(s\ \mu M)^{-1}$ on water and urea pools, respectively. Outer-sphere contrast agent doping (Fig. 2) yielded Nanomag®-SPIO-D relaxivities of $1.4x10^{-3}$ and $1.8x10^{-3}$ $(s\ \mu g/mL)^{-1}$ on water and urea pools, respectively. All relaxivities incorporate the effects of urea-water chemical exchange. Because the $MnCl_2$ relaxivity for urea is much lower than that for water, it provides a means of effectively independently controlling the water pool T_2. When both inner- and outer-sphere contrast agents are used concomitantly, a wide, continuous range of phantom T_2 combinations becomes accessible. Phantom formulations over possible T_2 ranges at different field strengths will be presented, and the effects of different outer-sphere contrast agents on urea relaxivity will be demonstrated.

References: 1) Jones, C., MacKay, A., and Rutt, B. "Biexponential T2 Decay in Dairy Cream Phantoms." *Mag. Res. Imag.*, Vol. 16, No. 1, pp. 83-85, 1998. 2) Lee, J.H., Labadie, C., Springer, C.S. Jr., and Harbison, G.S. "Two-Dimensional Inverse Laplace Transform NMR: Altered Relaxation Times Allow Detection of Exchange Correlation." *J. Am. Chem. Soc.*, Vol. 115, pp. 7761-7764, 1993.

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Figure 1: T2 Spectra over $MnCl_2$ Concentration Series

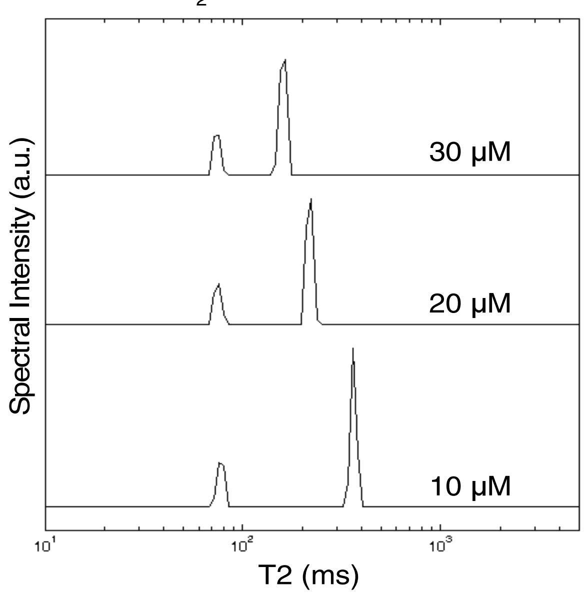

Figure 2: T2 Spectra over Nanomag-SPIO-D Concentration Series