Paramagnetic Ion Phantom to Independently Tune T1 and T2

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Purpose: Phantoms are used in MRI to test sequences, coils and systems, and a phantom should match the tissue relaxation properties. The National Institute of Standards and Technology (NIST) in collaboration with the ISMRM created a system phantom that mimics a range of T1 (NiCl2 array) and T2 (MnCl2 array) values [1]. These arrays contain single paramagnetic ions, and thus cannot vary T1 and T2 independently. Tissue mimics require independent control of T1 and T2 relaxation rates. In addition, an ideal phantom is shelf stable. A combination of paramagnetic ions in aqueous solution can be mixed and sealed to create a tissue phantom where T1 and T2 are independently tuned [2]. We tested the methods set forth by Schneiders to create an adipose tissue relaxation phantom and measured stability over 19 months.

Methods: Using the theory set forth by Schneiders and the relationship $V_1C_1 = V_2C_2$, we determined the following equations to independently set T1 and T2 using a combination of two paramagnetic ions in water:

$$V_M = \frac{[R_2(r_{1W} - S_N r_{1N}) + R_1(S_N r_{2N} - r_{2W}) + S_N(r_{1N}r_{2W} - r_{1W}r_{2N})]V_{total}}{R_2(S_N r_{1N} - S_M r_{1M}) + R_1(S_M r_{2M} - S_N r_{2N}) + S_N S_M(r_{1M}r_{2N} - r_{1N}r_{2M})}$$

$$V_N = \frac{[R_2(r_{1W} - S_M r_{1M}) + R_1(S_M r_{2M} - r_{2W}) + S_M(r_{1M}r_{2W} - r_{1W}r_{2M})]V_{total}}{R_2(S_M r_{1M} - S_N r_{1N}) + R_1(S_N r_{2N} - S_M r_{2M}) + S_N S_M(r_{1N}r_{2M} - r_{1M}r_{2N})}$$

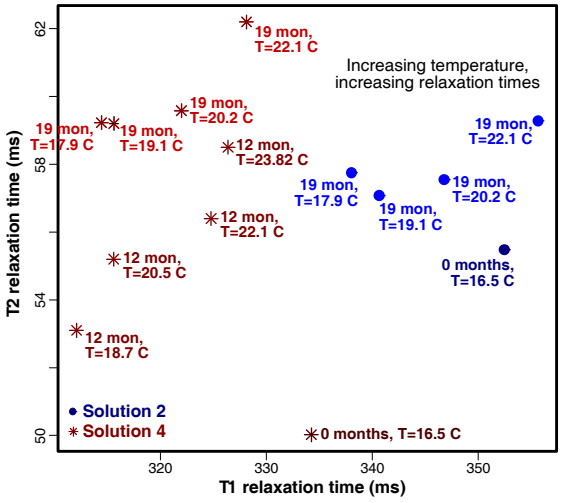
where V is the volume of paramagnetic ion stock solution (mL), R_1 and R_2 are the desired relaxation rates (s^{-1}), V_{total} is the total desired sample volume (mL), S is the concentration of the stock solutions (mM), and r_1 and r_2 are the empirically determined relaxivities ($s^{-1}mM^{-1}$). We empirically determined the relaxivities for $NiCl_2$ and $MnCl_2$ at 1.5 T and 20°C (Table 1). Then, we determined the required concentrations to match the T1 and T2 of adipose tissue in the breast at 1.5 T (T1: 296-372 ms, T2: 53 ms) [3], mixed the paramagnetic ion solutions, and sealed the solutions in standard polypropylene tubes. Tubes were stored in the MR laboratory for 19 months. T1 and T2 relaxation times were measured using inversion recovery and spin echo methods, respectively, at 0 (all solutions), 12 (solution 4) and 19 (solutions 2 and 4) months on a small-bore 1.5 T system. Measurements at 12 and 19 months were made in temperature-controlled environment; temperature control varies by ±0.011°C.

Table 1: Material	Stock (mM)	r_1 ($s^{-1}mM^{-1}$)	r_2 ($s^{-1}mM^{-1}$)
$MnCl_2$	2.23	7.2	75.4
$NiCl_2$	9.89	0.65	0.65
H_2O	1	0.35	0.4

Results: T1 was within ±4% of targeted values while T2 was under the targeted values by up to 13% (Table 2). Using the nearest temperatures (16.5, 18.73 and 17.91°C for 0, 12 and 19 months), the T1 values of solution 4 decreased by 11.5% at 12 months and 10.8% at 19 months. The T2 values decreased by 4.3% at 12 months and increased by 6.75% at 19 months. At a given measurement session, the T1 and T2 values increased with increasing temperature (Fig. 1).

Table 2: Solution	Target T1 (ms)	Target T2 (ms)	$MnCl_2$ (mM)	$NiCl_2$ (mM)	Measured T1 (ms)	Measured T2 (ms)	T1% error	T2% error
1	324.75	48.45	0.349	2.033	332.66	46.37	2.44	-4.29
2	334.8	53.45	0.317	2.259	334.26	50.02	-0.16	-6.42
3	349.5	57.9	0.381	2.033	343.66	54.73	-1.67	-5.47
4	367.5	63.8	0.254	2.259	352.46	55.48	-4.09	-13.04

Fig. 1: Stability of Paramagnetic Ion Solutions



Discussion: Our results show $NiCl_2$ and $MnCl_2$ can be used to tune T1 and T2 relaxation times independently. This study was limited by the use of different inversion times and different echo times in the T1 and T2 measurements at the 0, 12 and 19 month timepoints. Given that limitation, the solutions show stability within 10% change over 19 months. The $NiCl_2$ and $MnCl_2$ solutions are sensitive to temperature, and this is a limitation of these phantoms. Temperature variation may explain difference between expected T1, T2 and measured values. We will examine the results again after correcting for the $NiCl_2$ and $MnCl_2$ temperature dependencies.

Conclusion: The method presented by Schneiders can be used to tune both T1 and T2 relaxation time using $NiCl_2$ and $MnCl_2$ in aqueous solution. This method could be used to create solutions with constant T2 and variable T1 and vice versa, which are useful for tissue mimicking phantoms.

References: [1] Russek SE et al, 20th ISMRM 2012. [2] Schneiders NJ. Medical Physics 15:12-16, 1988. [3] Rakow-Penner et al., JMRI 23:87-91, 2006.