Quantitative interpretation of magnetization transfer in spoiled gradient echo MRI sequences

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Introduction A new signal equation derived in terms of a two pool model of magnetization transfer (MT) is given for the interpretation of spoiled gradient echo sequences employing off-resonance MT pulses. Validated experimentally, this technique demonstrates the feasibility of using standard clinical MRI scanners to measure the sizes of the two spin pools and their respective exchange and relaxation rates in an imaging context.

Methods We employ a binary spin bath model [1] which accounts for direct saturation of the free water pool due to off-resonance irradiation as well as saturation due to MT. The behaviour of the restricted pool is modeled using Provotorov theory with the inverse spin temperature interpreted as magnetization using the Curie law [4] and exchange with the dipolar reservoir neglected. This model has been shown [2] to accurately account for the behavior of materials driven to steady state under continuous wave RF irradiation.

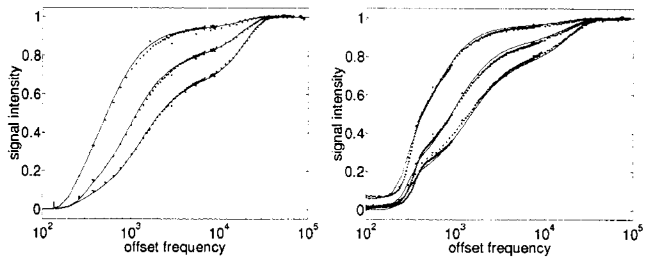
While the exchange and relaxation rates of biological tissues allow for a steady state to be rapidly established under normal imaging conditions, most clinical scanners are not able to provide continuous RF irradiation. Our solution to this problem is to view the imaging sequence as periodic in time and decompose it into a Fourier series. Each spectral component of the irradiation results in a transition rate for the restricted pool which is in proportion to the lineshape and RF power at that frequency. These components add to yield a single transition rate which for our experiments is dominated by the component at the center frequency of the shaped off-resonance MT pulses.

Since the response of the free pool to the off-resonance pulses is oscillatory at most of the offset frequencies of interest, we dispense with the Fourier series interpretation for the free pool and account for individual pulses in terms of their fractional saturation of the longitudinal magnetization. Combining the two models, a sequence is composed of periods in which the bound pool undergoes continuous irradiation and exchange with the free pool, interspersed with events which partially saturate the free pool. Following the derivation of [3], we use this process to derive a signal equation for a spoiled gradient echo sequence in steady state as a function of the various pool sizes, relaxation and exchange rates as well as the saturation fraction and transition rate of the given MT pulse.

To validate our signal equation, we analyzed various concentrations of agar gel, a material whose MT properties are well characterized [1] by the binary spin bath model and a Lorentzian lineshape for the restricted component. For our experiments, we used a spoiled gradient echo sequence (SPGR) (TR/TE = 50 ms/4 ms) incorporating 10.2 ms shaped MT pulses whose offset frequency and power could be varied. The properties of a particular sample were determined by fitting the signal equation to measurements made for a range of pulse powers and offset frequencies. As further validation, we compared our results to experiments analogous to those used in [1] in which the spins were prepared using unspoiled MT pulses repeated every 15 ms to establish a steady state before measuring the signal using phase cycled 90 degree pulses.

Results The results of fitting our signal equation to the two types of experiments performed on 4% agar are shown in Figure 1. The properties of the material determined by the two techniques are given in the following table, where k_f is the forward exchange rate, f is the fractional size of the restricted pool, and the subscripts $_f$ and $_r$ denoted relaxation of the free or restricted pools.

	MT prepared sequence	SPGR MT sequence
k_f	2.06 $\pm$1.6 s^{-1}	1.64 $\pm$3.0 s^{-1}
f	0.0137 $\pm$0.0015	0.0116 $\pm$0.0034
$T1_f$	1.46 s	1.46 s
$T1_r$	1.0 s	1.0 s
$T2_f$	28.9 $\pm$0.7 ms	25.1 $\pm$1.3 ms
$T2_r$	13.8 $\pm$0.8 μs	13.4 $\pm$2 μs



MT prepared sequence SPGR MT sequence

Figure 1: Comparison of experimental data (dots) and model (lines) for three different pulse powers

Conclusions As can been seen from these results as well from results not shown for 2% agar, the fit of the model to the data is good and the estimated parameters, with the exception of $T2_f$, agree with each other and with values in the literature [1]. While we have collected a large number of data points in order to validate our model, in practice a small subset of this data can be used to estimate the parameters. These data points can be acquired rapidly as a series gradient echo images making it feasible to use this technique to determine these parameters from images acquired *in vivo*.

References

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