Magnetization transfer contrast enhancement due to intermolecular multiple quantum coherences - quantitative analysis and tissue dependency

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Introduction

Recently published studies [1,2], showed an increased sensitivity of intermolecular multiple quantum coherences (iMQC) to magnetization transfer (MT) effects compared to single quantum coherences (SQC). The image contrast in magnetization transfer contrast (MTC) MRI is proportional to $(M_z/M_0)^n$, where M_z is the actual longitudinal magnetization, M_0 is the equilibrium magnetization and n denotes the order of the quantum coherence used (n=1 for SQC, n=2 for iDQC and so on). The aim of this work was to quantify this contrast enhancement and to determine the dependency of this effect on the tissue used. Experiments were performed on a 9.4-T animal scanner.

Methods

Different types of tissue were simulated by two Agar water phantoms with 1% and 2% Agar gel concentration. The pulse sequence used consisted of a MT module with off-resonance rf-pulses followed by a CRAZED (Cosy Revamped by Asymmetric Z-Gradient Echo Detection) sequence and an EPI readout. The Agar gel model parameters were derived by fitting the normalized signal intensities of 5 series of SQC (n = 1) measurements with 5 different strengths of the off-resonance pulses (2.5 μT, 5 μT, 10 μT, 20 μT and 40 μT) according to the standard 2 pool model [3]. Each series consisted of 100 data points corresponding to 100 offset frequencies Δ between 1 Hz and 100 kHz. For the iDQC experiment one set with 100 offset frequencies Δ between 1 Hz and 100 kHz were measured (the strength of the off-resonance pulse was 10 μT). A *modified* 2 pool model which includes the $(M_z/M_0)^n$ dependency and the previously determined model parameters (SQC), which only depend on the chemical environment and *not* on the order of coherence, was used to fit the iDQC data.

Results

Figure 1a shows the SQC, iDQC and water data and the corresponding fits for the 2% Agar water phantom. The shaded regions between the curves in Figure 1b visualize the saturation due to MT. Table 1 shows the quality of the fits according to the modified and the unmodified model (the fits according to the unmodified model are not shown. An iTQC measurement was not possible in 2% Agar because of low SNR. Figure 2a and 2b illustrate the MT on 1% and 2% Agar for SQC and iDQC preparation respectively. Figure 2c and 2e visualize the saturation while 2d shows the differences in relative signal intensity between 1% and 2% Agar for SQC and iDQC preparation.

Discussion

An enhanced MT effect with increasing order of coherence n (highlighted by the yellow arrows) is visible in Figure 1. The fit qualities shown in Table 1 clearly indicate the necessity for a modification of the standard 2 pool model which includes the order of coherence n. Figure 2 shows a stronger MTC for the 2% Agar gel for both SQC and iDQC preparation. This is in agreement with the expectations since there are more spins in the bound pool, which can be saturated. Figure 2d shows a stronger difference in MTC between the Agar gel concentrations for iDQC preparation compared to SQC preparation. For the iDQC preparation the maximum in the MTC difference is reached at higher offset frequencies (4.3 kHz compared to 1.8 kHz for SQC). These differences could be used in following studies to gain additional tissue contrast.

References

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[3] Henkelman, R.M. *et al*., Magn. Reson. Med., 29:759–766.

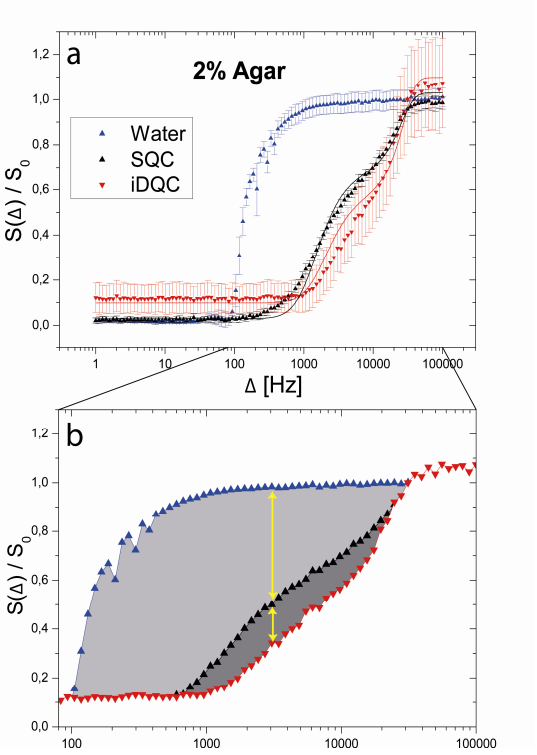

Figure 1: *(a) shows the measured data for the SQC and iMQC preparation and for pure water. (b) illustrates the contrast enhancement due to MT.*

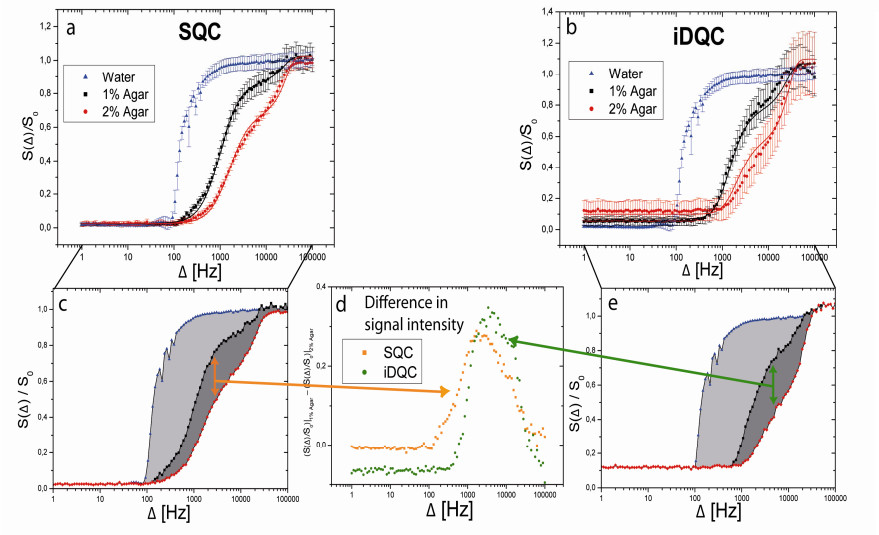

Figure 2: *(a) and (b) show the MT for 1% and 2% Agar for SQC and iDQC preparation. (c) and (e) illustrate the MT due to saturation. (d) shows the differences between both.*

		1% Agar		2% Agar
Preparation		iDQC	iTQC	iDQC
SQC-Fit (n=1)	χ^2	0.0049	0.0530	0.0148
	R^2	0.9677	0.1916	0.8600
iDQC-Fit (n=2)	χ^2	0.00085		0.0013
	R^2	0.9945		0.9877
iTQC-Fit (n=3)	χ^2		0.0150	
	R^2		0.7706	

Table 1: *The quality of the fits on the iMQC data for modified and unmodified fitting functions.*