Quantitative MT measurement - is 3T the solution or the problem?

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Introduction

Most quantitative models of magnetization transfer (MT) [1] express the signal as a function of several parameters, which can be estimated by fitting the model to data collected at a range of saturating powers (ω) and frequencies (Δ). The number of independent variables involved and the non-linear nature of the two-pool model (which makes it very sensitive to noise) make the increased signal-to-noise ratio (SNR) at field strengths higher than 1.5T appealing. Moving to higher field, however, also involves changes to relaxation times, and increased problems from B_0 and B_1 inhomogeneity. Furthermore, safety issues associated with the deposition of RF energy into the patient, measured by the specific absorption rate (SAR), must be considered. Here we set up optimal MT acquisition protocols at 1.5T and 3T, and we address the question of whether the SNR benefits at 3T outweigh the disadvantages.

Methods

This work is based on the MT model developed by Ramani et al. [2], where signal is expressed as a function of 7 parameters (S_0, R_A, R_B, RM_0^B, F, T_2^A and T_2^B, where $F=M_0^B/M_0^A$, 'A' labels the liquid pool, and 'B' labels the macromolecular pool). In Ramani's model, the MT pulse is replaced by continuous wave irradiation with the same mean square amplitude. *__Simulations:__* We consider the case of a pulsed MT spoiled gradient echo acquisition, with short (e.g. for 3D sequences, ≈TR/2) Gaussian MT pulses applied once every TR [3], and we assume the longitudinal relaxation rate of the system, R_{Aobs}, is independently measured [1]. We make the following assumptions:1) T_1 is longer and T_2 is shorter at 3.0 T [4]; 2) MT parameters are field independent [1]; 3) SAR is increased at 3.0T, imposing tighter constraints on the maximum ω; 4) SNR (before taking relaxation and acquisition effects into account) is doubled at 3.0T. The parameters used to create simulations are shown in Table 1. We compare 3 cases, a 15-point acquisition at 1.5T (TR=28ms, flip angle=5°), a 15 point acquisition at 3T (TR=28ms, flip angle=4°), and a 10 point acquisition at 3T (TR=42ms, flip angle=5°). The 3 combinations of TR and flip angle ensure an equal degree of T_1-weighting (in the absence of MT saturation), while requiring the same total scan time. The combinations of ω and Δ for each case were computed according to [5]. We generated 3 noise-free synthetic sets by solving the coupled Bloch equations for the system [1,6], and adding Rician noise before fitting Ramani's model to the data. The standard deviation of the Gaussian real and imaginary parts of the noise (σ_n) is calculated to give a range of signal-to-noise ratios (SNR) between 20 and 300 for the 1.5T data, while we assume σ_n to be halved for the same type of acquisition at 3.0T. We generated 10000 Monte Carlo sets for each SNR level to measure the mean and standard deviation of 4 parameter estimates (RM_0^B, T_2^B, T_2^A and F). *__In vivo data:__* A single healthy male subject (40 year old) was scanned once on a 1.5T, and twice on a 3.0T system, each time collecting A) a 3D MT-weighted fast SPGR (TE=3.1 ms), which was repeated 3 times, each time collecting either 10 or 15 volumes according to the protocol [3]; B) 3 fast SPGRs with different flip angles (5˚,15˚,25˚ at 1.5T; 3˚,7˚,15˚ at 3T) for T_1-mapping; C) 2 fast recovery FSEs with differing flip angles for B_1 mapping; D) 2 SPGRs for B_0-mapping. The parameters specific to each MT session matched those used to build up the simulations. B_1 maps were obtained from sequence C using the double angle method [7] and B_0 maps were obtained from sequence D [8]. T_1 maps were calculated from sequence B as described in [3]. Next, for each of the three protocols, 1000 MT sets for each scheme were generated by a bootstrapping procedure. The model was fitted to each bootstrapped sample correcting ω and Δ based on the field maps, providing 1000 estimates of RM_0^B, F, T_2^B, and T_2^A. We computed the Coefficient of Variance (COV = the SD divided by the mean across the 1000 samples) of the MT parameters in each voxel.

Results

As expected, the simulations showed that the estimation of all parameters is more *precise* at 3T than at 1.5T. For SNR>50, however, F was more *accurately* estimated at 1.5T. Between the two protocols designed for 3T, the short-TR 15-point acquisition provided both more accurate and more precise estimates of RM_0^B, F, T_2^B (the results for F are shown in Fig 1 as an example). T_2^A was overestimated in all 3 cases by approximately 20% of its value. The mean CoVs across 1000 bootstrap samples (Table 2) confirmed that the 15 point short-TR protocol at 3T (3Tb) provides the most precise estimates for all parameters, while the 10 point long-TR acquisition at 3T (3Ta) does not seem to improve parameter estimation compared to the 15 point 1.5T acquisition. Moreover, the CoVs measured at 3T are less homogeneous across different ROIs than at 1.5T, probably due to the effect of B_0 and B_1 inhomogeneities.

	1.5 T	*3.0 T*
RM_0^B [s^{-1}]	3.4	3.4
F	0.12	0.12
R_A [s]	1.69	1.35
T_2^A [s]	0.8	0.7
T_2^B[μs]	10.0	10.0
T_2*[s]	0.066	0.053

Table 1.
MT&Relaxation parameters used to create simulations [see refs 2,3,4,10].

	Frontal wm			*cc-splenium*			*thalamus*		
	1.5T	3Ta	3Tb	1.5T	3Ta	3Tb	1.5T	3Ta	3Tb
RM_0^B	10.8	12.4	3.7	9.8	8.1	5.3	8.7	6.5	3.6
F	6.7	8.7	3.7	6.2	7.8	7.3	5.6	5.9	3.5
T_2^A	4.1	23.5	5.9	4.2	18.3	5.3	4.3	5.1	2.6
T_2^B	6.5	5.6	2.3	4.6	4.4	3.8	4.3	3.1	2.0

Table 2.
Mean parameter Coefficient of Variance (CoV) expressed in percentage units, across 1000 bootstrapped samples, estimated in 3 regions of interest. For bilateral structures, the value shown is the average of left and right.
'cc-splenium'=splenium of corpus callosum.
3Ta = 10 point acquisition, 3Tb=15 point acquisition.

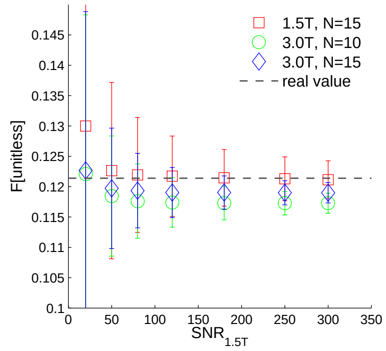

Fig 1. Plot of mean (±SD) F from 10000 MonteCarlo simulations against SNR in the unweighted image at 1.5T for 3 protocols.

Discussion

Although the increased SNR at 3T improves the precision of the estimated MT parameters, the accuracy is not always increased. Furthermore, the superiority of the 'short TR 15 point' compared to the 'long TR 10 point' protocol at 3T suggests that for an acquisition scheme with a relatively small number of points (as those considered here) the available time should be used to collect as many points as possible rather than to increase the SNR of each measurement. These results are likely to generalize to other (than Ramani's) approximations of the two-pool model. As it was recently shown that a potential bias is introduced by measurements at Δ<1kHz [9], we intend to repeat both simulations and measurements for optimal schemes computed under this constraint. Future work will also include a formal analsyis of the effects of field inhomogeneities.

References

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