QUANTIFICATION OF MT PARAMETERS IN VIVO AND OPTIMIZATION OF MTR ACQUISITION AT 3.0 T

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Introduction: Despite the potential advantages in terms of signal-to-noise ratio (SNR), the use of magnetization transfer (MT) at 3.0 T is still limited, mainly due to potential specific absorption rate (SAR) issues. The MT effect has been fully characterized under continuous RF irradiation[1] using a two-pool model (liquid and semi-solid pool, herein labelled A and B), which predicts the signal behaviour as a function of the fully relaxed values of magnetisation associated with the two pools (M_0^A and M_0^B), their longitudinal relaxation rates (R_A and R_B), their rate of loss of longitudinal magnetization due to the RF irradiation (R_{RFA} and R_{RFB}), and the exchange rate R. Graham and Henkelman showed that it is possible to exploit this model to estimate the optimal parameters for MT acquisition for a given application[2] . Using a similar approach, we derived the optimal acquisition parameters for a 3D MT ratio (MTR) acquisition at 3.0 T as a compromise between maximising WM-to-grey matter (GM) contrast-to-noise ratio (CNR) on MTR maps, while minimising the so-called direct effect, i.e. the direct saturation of the liquid pool in absence of exchange due to off-resonance irradiation. As the values of the Henkelman model parameters have not been previously reported at 3.0 T, we first performed a series of measurements to estimate these, and then used the values derived to optimise the MTR measurement.

Methods: One subject (female, 32 years) was scanned on separate sessions on a 3.0 T scanner (GE Signa) using a 3D spoiled gradient recalled echo (SPGR) sequence (TR = 20 ms, TE= 4.1 ms, flip angle=5º, matrix = 256x192x52, in-plane FOV=240x180x156), with Gaussian MT pulses (duration=7.3 ms). The sequence collects two volumes, with and without MT saturation, in a total scan time of 5 minutes. The average SAR over time was kept under observation during all acquisitions using the manufacturer's 6 minutes average SAR monitoring. The manufacturer's body coil was used for transmission, and their 8 channel head coil was used for signal reception. Eight dataset with different combinations of MT pulse amplitudes and offset frequencies were obtained. Two RF powers were used, described by their equivalent on-resonance flip angles (250º, 400º). For each power, 4 offset frequencies (Δ=1,2,4,and 7 kHz) were used. RF amplitude (expressed as an angular frequency) corresponding to each flip angle was estimated as the continuous wave power equivalent (CWPE)[3], giving respectively ω_1=439 and ω_2=703 rad/sec. The signal was measured on each MT saturated image in two regions of interest, one placed in WM (genu of the corpus callosum) and one placed in deep gray GM (putamen), and normalised with respect to the corresponding signal on the unsaturated image. The Henkelman-Ramani model[3] was then fitted to these data points, leading to a set of estimated parameters for both WM and GM. The fitted parameters were then used to obtain estimates of the WM and GM signal on MTR images at 3.0 T (MTR_{WM}, MTR_{GM}). The propagation of error equation[4] was used to estimate the variance of signal on MTR maps, relative to the variance on the collected images. CNR was then estimated as:

$$CNR = \frac{\left(MTR_{WM} - MTR_{GM}\right)}{\frac{1}{2}\sqrt{\sigma^2_{MTR_{WM}}} + \frac{1}{2}\sqrt{\sigma^2_{MTR_{GM}}}}$$

The direct effect was estimated by setting R=0 and M_0^B =0 in the same model[1]. As explicit knowledge of R_A is required in this case, representative values of the observed R_A, measured by others[5] at 3.0 T, were used (R_A(WM) = 1.17 sec^{-1}, R_A(GM) = 0.83 sec^{-1}).

Results: The MTR maps obtained at 3.0 T were of very good quality, demonstrating excellent SNR and contrast. Fig 1A shows the normalised MT-weighted signal at different powers and frequencies, together with plots of the signal from the WM and GM ROIs, showing the excellent fit to the model. The parameters obtained from the fitting are reported in table 1. Fig 1B shows the predicted CNR on MTR images as a function of ω. The maximum CNR occurs at a range of powers 620<ω<640 rad/sec for Δ=2 kHz (CNR=0.09). Fig 1C shows the estimated MTR as a function of Δ, for ω=630 rad/sec. The red line represents the proportion of MTR due to direct effect. The ideal offset frequency for a given RF power corresponds to the value where the difference between the MTR and the direct effect is at its maximum[6]. This value was found for Δ≈1.8 kHz, remaining fairly constant up to Δ=2 kHz (the value for which the contrast was optimized). Fig 2 shows an MTR maps obtained with the ideal parameters (ω_{CWPE}≈630 rad/sec, Δ=2 kHz), together with other two examples obtained with different combinations of ω and Δ.

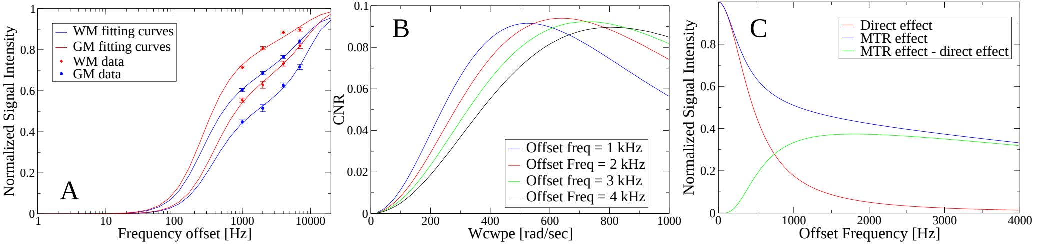

Fig 1. A) Experimental data (symbols) and fitting curves (solid line) for WM (blue) and grey matter (red). B) CNR as a function of MT pulse RF power. C) MT effect (blue), direct effect (red) and their difference for ω=620 rad/sec in WM.

	RM_0^A	f*/R_A(1-f)	T_{2B} [μSec]	1/R_AT_{2A}	R_B (fixed)
WM	28.0	0.08	11.7	20.4	1
GM	64.8	0.04	10.2	17.5	1

Table 1. Henkelman-Ramani model's parameters fitted to experimental data. *$f=M_0^B/(M_0^A + M_0^B)$.

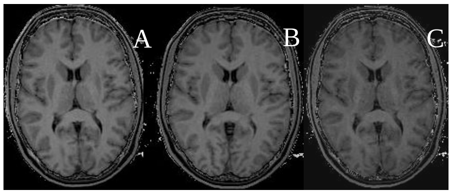

Fig 2. MTR maps obtained with optimized acquisition (A), with ω =440 rad/sec and Δ=1 kHz (B), with ω =700 rad/sec and Δ=7 kHz (C).

Discussion: We have demonstrated that MTR acquisition is feasible at 3.0 T, leading remarkable SNR and WM-to-GM CNR, as shown by the MTR maps in Fig 2. We used several simplifications in modelling the signal, also neglecting the effects of TR and imaging flip angle on contrast, assuming it is the same for the saturated and unsaturated image. These approximations have the advantage of simplifying calculations compared to the use of exact models for pulsed MT[6], without introducing large errors. Finally, to our knowledge, this is the first attempt to measure MT parameters in vivo at 3.0 T. Although our measurements were obtained from a single subject and only two areas of the brain, the values reported in Table 1 are in keeping with those measured at 1.5 T, after accounting for the (expected) difference in R_A. This is consistent with what observed by Henkelman[1] i.e. that MT related parameters are field independent.

References

1.Henkelman RM et al. MRM 29: 759 (1993); 2. Graham J, Henkelman RM. Radiology 212: 903 (1999); 3. Ramani A et al. MRI 20:721 (2002); 4. Bevington PR. McGraw-Hill, New York (1969); 5. Clare S, Jezzard P. MRM 45:630 (2001); 6. Garham J, Henkelman RM. JMRI 5: 903 (1997).