CNR-optimised MT mapping for improved visualisation of the substantia nigra

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TARGET AUDIENCE: MRI physicists with an interest in MT and optimisation

PURPOSE It was shown recently that a multi-parametric imaging method based on magnetization transfer (MT) is able to provide a quantitative map, denominated "MT saturation" (δ), which provides exquisite contrast between subcortical grey matter and the surrounding white matter (WM) (1). A protocol optimized for imaging of the thalamus using this novel approach at 3T has been presented (2). The purpose of this paper is to select the best combination of acquisition parameters within clinically acceptable times at 1.5T to maximize the contrast-to-noise ratio (CNR) between the substantia nigra (SN) and the surrounding white matter. This optimization is carried out as part of a project focusing on the role of the SN in attention deficit hyperactive disorder.

MATERIAL AND METHODS

Theory**:** Based on the model of the signal measured in a MT-weighted spoiled gradient echo acquisition (S_{MT}) presented in (1), we can estimate δ as:

$$\delta = (A\,\alpha/S_{MT} - 1)R_1 TR - \alpha^2/2, \quad \text{[eq 1]}$$

Where A is the amplitude of the echo at the echo time, R_1 is the inverse of T_1, and α is the imaging flip angle. Therefore we define the contrast, C, as difference between the MT saturation value in the substantia nigra (δ_{SN}) and the MT saturation value in the WM (δ_{WM}). Since the choice of the acquisition parameters also affects the signal-to-noise ratio (SNR) of the δ maps, we use the propagation of error equation (3) to estimate the variance of the signal in δ maps, relative to the variance of the S_{MT}:

$$var(\delta) = \frac{\partial\delta}{\partial S_{MT}} = A\,\alpha R_1 TR/S_{MT}^2 \quad \text{[eq 2]}$$

With knowledge of the quantitative MT parameters of the anatomical areas of interest, it is thus possible to use Sled and Pike's model of MT signal (4) to simulate S_{MT} in both, eqs 1 and 2.The CNR can then be estimated as:

$$CNR = \frac{\delta_{WM} - \delta_{SN}}{1/2\sqrt{var(\delta_{SN}) + var(\delta_{WM})}} \quad \text{[eq 3]}$$

Simulations: We used 5 datasets from a local image database, which includes a full quantitative MT protocol, which enables the calculation of a full set of quantitative MT parameters (R_1, T_{2f}, T_{2r}, k_f, F), based on Sled & Pike's model (4). The MT parameters of the SN and adjacent WM were estimated from 5 young healthy participants. Four regions of interest (ROIs) (right and left SN, and right and left cerebral peduncles) were manually outlined on the proton-density (PD) weighted scans, and estimates of the quantitative MT parameters were obtained from corresponding parametric maps. Values from left and right hemisphere were pooled, and then averaged across subjects. These values were used to estimate S_{MT} for either tissue in equations 1 and 2. Each equation was evaluated for the following range of acquisition parameters: TR ranging from 20 to 30 ms, α ranging from 3° to 15°, the MT pulse power (ω), ranging from 200 to 900 rad/s, and the MT pulse offset frequency (Δ), ranging from 1 to 5 kHz. The resulting values were thus used to estimate the CNR as a function of the acquisition parameters. MRI: A healthy participant (male, 24 years of age) was scanned on a 1.5T system collecting the following datasets: 1. A PD-weighted multi-echo 3D FLASH (4 echoes, TEs ranging from 2.51 to 10.82 ms, TR=24, α=6°); 2. A T1-weighted 3D FLASH (4 echoes, same TEs as PD-weighted one, TR=19 ms, α=6°); 3. Three MT-weighted 3D FLASH sequences (4 echoes, same TEs as previous sequences) with 3 different combinations of TR, α, ω, and Δ, based on the results of simulations. Image Analysis: Maps of A, R_1 and δ (one for each of 3 MT acquisitions) were obtained as described in (1). Four ROIs, matching those used for MT parameters estimation, were manually outlined on the PD-weighted scan. Values were then obtained for each of the 3 δ maps. Values from the right and left hemispheres were averaged. The relative contrast was estimated for each as $C_r=(\delta_{WM}-\delta_{SN})/(\delta_{WM}+\delta_{SN})$.The maps were then segmented using SPM8 to evaluate the improvement in separating the SN from other tissues when using the optimal parameters.

RESULTS

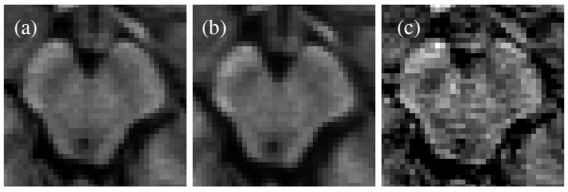

Figure 1. *MT images of the SN using 3sets of acquisition parameters.(a) Shows an optimal acquisition. (b) (SUB1) and (c) (SUB2) show sub-optimal acquisition parameters.*

The maximum CNR was obtained for TR=30ms, α=12°, ω=900 rad/s, Δ= 1kHz. The optimal acquisition (OPT) was compared with the following: SUB1: TR=24ms, α=6°, ω=900 rad/s, Δ= 1kHz, and SUB2: TR=30ms, α=12°, ω=300 rad/s, Δ= 3kHz. C_r was found to be 0.126 for OPT, 0.088 for SUB1, and 0.160 for SUB2. Although C_r for SUB2 was higher than for OPT, the image was extremely noisy (see Fig1) and thus not suitable for segmentation. The results of segmenting the δ maps obtained from OPT and SUB1 are shown in Fig 2.

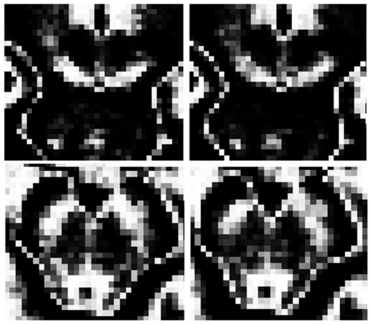

Figure 2.S*egmentation of an optimal acquisition (left). Segmentation of a suboptimal acquisition (right).*

DISCUSSION Our simulations suggest that the MT saturation should be maximised in order to improve the CNR between the SN and the surrounding WM. The optimal combination of TR and α is slightly different than that found in (2), but it should be noted that, first, they optimised the SNR instead of the CNR; second, they were interested in the thalamus, instead of the SN, and, finally, their optimisation was carried out for 3T acquisition, instead of 1.5T. In vivo data confirmed the results of simulations, and the quality of the segmentation (Fig 2) supports the use of the optimal acquisition.

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