Insight into Neuromelanin-MRI Z-spectrum contrast of the Substantia Nigra

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Target audience: Neuroradiologists, investigators interested in Parkinson disease.

Purpose: Neuromelanin-sensitive MRI[1] typically uses a multi-slice 2D turbo-spin-echo sequence (TSE) with a magnetization transfer (MT) prepulse to improve the observable contrast of neuromelanin (NM) containing structures, such as the substantia nigra (SN) and locus coeruleus (LC), relative to surrounding tissues. The underlying contrast mechanism is thought to be the paramagnetic T1-shortening effect of NM and associated iron, and adding an MT-prepulse enhances NM-containing tissue relative to the suppressed background brain tissue signal[2]. It has been recently shown that the use of gradient echo (GRE) sequences with MT preparation pulse can also be used to simultaneously image the SN and LC[3]. As the magnitude of MT effect depends on the offset frequency, optimizing NM-MRI contrast should benefit from characterizing the z-spectrum of relevant tissues. The purpose of the study was to assess the effect of the MT pulses by examining the z-spectra of the SN and its surrounding tissues in TSE and GRE images.

Methods: We examined 5 healthy volunteers (2 males, 3 females; aged 25-49, mean 34 years) using a 3T MRI scanner (Achieva, Philips Medical Systems, the Netherlands) with a 32-channel head coil. We performed a series of experiments using a multi-slice T1-weighted TSE sequence with the following base parameters: TE/TR = 12/670 ms, turbo factor = 4, FoV = 216 x 164 mm^2, acquisition/reconstruction resolution = 0.8x0.8x4.0 mm / 0.5x0.5x4.0 mm, gap = 4.0 mm, 6 slices, acquisition time = 36 s. The base TSE sequence was acquired without MT prepulse (Fig. 1c), with the manufacturer's default 'on' and 'off' resonance MT prepulses (Fig. 1a,b), and with a 25 ms, non-selective single-lobed-sinc MT prepulse having a flip angle of 1040°, at 22 offset frequencies logarithmically spaced over 0.1-100 kHz for the production of a z-spectrum (acquisition time: 14 min) (Fig. 2a). A single-slice TSE acquisition with the same base parameters and off resonance MT (Fig. 1d) was performed to examine the effect caused by neighbouring slices.

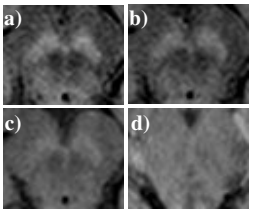

Fig. 1. a) on-resonance; **b)** off-resonance; **c)** no MT; **d)** single-slice off-resonance

A z-spectrum was also obtained using a 3D spoiled gradient echo (SPGR) sequence with EPI readout (TR/TE/α = 55.5 ms/10.14 ms/12°, EPI factor = 9, FoV = 232 x 192 mm^2, acquisition/reconstruction resolution = 1.0x1.38x4.0 mm / 0.5x0.5x4.0 mm, 12 slices, 2 signal averages, acquisition time = 5 min), and the same MT prepulse parameters as above. Images were acquired in an oblique axial plane perpendicular to the floor of the fourth ventricle. Data were processed using a custom-written program in Matlab (The Mathworks, Natick, MA, USA). Circular (4 mm diameter) ROI were defined in the SN and the cerebral crus (CC). The contrast ratio (CR) between the SN and the CC was calculated as: $CR = (I_{SN}-I_{CC})/I_{CC}$, where I_{SN} and I_{CC} are the respective averaged signal intensities. The CR was estimated for each frequency offset.

Results: Consistent with previous studies, the CR was enhanced with the addition of MT pulses, and a small but not significant difference was seen between 'on' and 'off' resonance prepulses ($CR_{on\text{-}res}$ = 0.19±0.04; $CR_{off\text{-}res}$ = 0.16±0.03, CR_{noMT} = 0.10±0.03). The z-spectra for ROIs placed in SN and CC (Fig. 2c,d) show that a maximum CR is observed at 835 Hz (CR_{TSE} = 0.21±0.03) and 1525 Hz (CR_{SPGR} = 0.17±0.05) for the TSE and SPGR sequences, respectively (Fig. 2b). For all subjects, the CR_{TSE} at 835 Hz was higher than the CR with the default 'on' and 'off' resonance MT prepulses. The single-slice TSE showed significantly lower NM contrast (CR_{1slice} = 0.03±0.01)

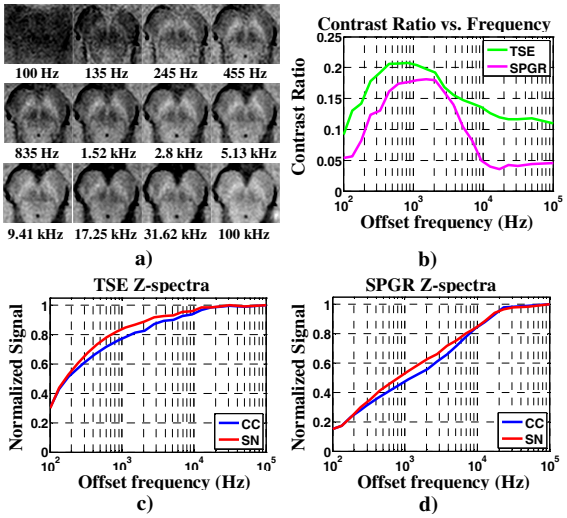

Fig. 2. a) Raw TSE MT images cropped to be centered around the SN (only 12 images are shown); **b)** Contrast ratio as a function of the offset frequency; **c)** TSE Z-spectra and **d)** SPGR Z-spectra of the substantia nigra (SN) and cerebral crus (CC)

Discussion and conclusion: In NM-MRI, the contrast between NM containing structures (i.e., SN and LC) and surrounding tissues is enhanced by adding a MT prepulse. In a multi-slice TSE the slice selective excitation and refocusing pulses of one slice act as off-resonance pulses for neighbouring slices, leading to increased MT effects on signal intensity. This latter is a direct function of the number of slices[4], but the combination of refocussing and MT prepulses can cause SAR to impose limitations on scan-time. This can become problematic when studying Parkinson's disease patients as the LC requires greater resolution and hence longer scan times than used in the present study where we focussed on SN contrast. Gradient echo sequences offer lower inherent SAR levels than with the TSE and MT preparation can be used to obtain NM contrast[3]. In fact, we found that the SPGR sequence with MT prepulse at a frequency offset in the range 600-2000 Hz showed similar CR to those using the TSE with default 'on' and 'off' resonance MT pulses, though slightly less than the optimal CR achieved with TSE and a MT prepulse at an offset of 835 Hz. In conclusion, the contrast of the SN using both TSE and GRE sequences can be optimized by using off-resonance MT pulses at or near 835 Hz and 1525 Hz respectively.

References:

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