

Paradoxical changes in magnetization transfer ratio and susceptibility contrast in the motor cortex

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Introduction

Myelination and iron content vary across the cortex depending on differences in laminar organisation [1]. Magnetization Transfer (MT) Imaging is generally used to study variations in myelination in the white matter (WM) and can also be used to study variations in myelin content across the cortex [2]. Additionally, phase images give information about susceptibility and exchange in tissue [3,4]. However to provide adequate sensitivity in MT or phase data at high spatial resolution, the data must be acquired at ultrahigh field (e.g. 7T). Here, we use pulsed train MT in conjunction with Turbo Field Echo (TFE) [5] at 7T to quantify changes in MT, and Fast Field Echo (FFE) images to measure the phase shifts between grey and white matter in different cortical areas.

Methods

Three healthy volunteers were scanned with local ethics committee approval, using a Philips Achieva 7T scanner. High resolution MPRAGE images were acquired with a tailored inversion pulse [6] to reduce effects of inhomogeneities on the final contrast. MT data were acquired using an MT-TFE sequence [4]: for the MT_{sat} image a TFE image was acquired after a saturation pulse chain; for the MT_{noSat} images the TFE volume was acquired without presaturation. Saturation pulse train: 20 off-resonance pulses, 13.5 μ T Gaussian-windowed, sinc pulses, with bandwidth 300 Hz and off-resonance by 1.0 kHz (3.4 ppm), 21 ms between each pulse. TFE readout: TR/TE=13/6.4 ms, flip angle= 8°, 0.5x0.5x0.6 mm³, FOV of 205x175x50 mm, centre-out sampling, NSA=2, shot to shot interval (SSI) of 10 s, imaging time of 13 min 50 s in total. High resolution MTR maps were calculated from $(MT_{noSat} - MT_{sat})/MT_{noSat}$ on a pixel by pixel basis after registration of the two volumes of interest. T₂*-images were acquired with a 3D FFE sequence (TR/TE=50/17 ms, flip angle=16°, acquisition time=9 min). After high-pass filtering the phase data were inverted to form susceptibility maps [3]. All data were registered to the MPRAGE volume, before drawing the ROIs. For each subject, 8 ROIs were defined (4 in the WM, 4 in the GM) in each of the 4 following areas: frontal lobe (FL), motor cortex (MC), occipital lobe (OL), and visual cortex (VC). Each WM region was drawn close to its paired GM region, to allow the contrast to be estimated, before averaging over the different brain areas. Visual check and manual correction were performed during the measurement to account for mis-registration errors. Results were averaged across subjects (fig. 2). Cortical MT was also overlaid on the cortical surface using Freesurfer [6] to display MT variation depending on the cortical depth.

Results

Figure 1 presents images from one representative subject, while Fig. 2 shows the signals measured in WM and GM and the GM/WM contrast averaged over 3 subjects. The T₁-weighted signal is relatively constant throughout the WM, but varies across the GM, particularly increasing in the motor cortex compared to the frontal lobe (Fig. 1). The same effect can be seen in the MTR maps, where the contrast is lowest in the motor cortex, suggesting greater myelination, although the WM MTR decreases as well. The surface rendering of the GM MT shows that this effect is not localized to a single slice but extends down the whole motor strip. Looking at the susceptibility data, the motor cortex shows a considerable increase in contrast compared to the other regions, with a difference of more than 0.03 ppm between the WM and the GM. This effect could be seen to a lesser extent in the occipital lobe (Figs. 2 and 3).

Discussion

Surprisingly decreased MTR contrast between GM and WM in the MC is associated with increased phase contrast between GM and WM in the susceptibility maps. Magnetic susceptibility and chemical exchange are two complementary factors influencing the susceptibility maps. It has recently been reported that the frequency shift between GM and WM due to chemical exchange is approximately equal and opposite to the frequency shift observed between GM and WM in vivo [3] suggesting that the frequency shift due to susceptibility is about twice the frequency shift observed between GM and WM in vivo. This suggests that if GM myelination increases, the local GM/WM contrast due to exchange will be attenuated, and the phase shift due to susceptibility will dominate explaining the increase in contrast on susceptibility maps accompanying a decrease in contrast on MTR maps in the MC. T₂ and T₂* of the MC are known to be reduced compared to other GM areas and it has previously been suggested that this is due to an increase in local iron content, though it could also be due to an increase in myelin content.

Fig. 2: ROIs measurements (A: T1 contrast, B: MTR, C: susceptibility) across subjects (N=3) over the WM, the GM and the contrast for different cortical areas.

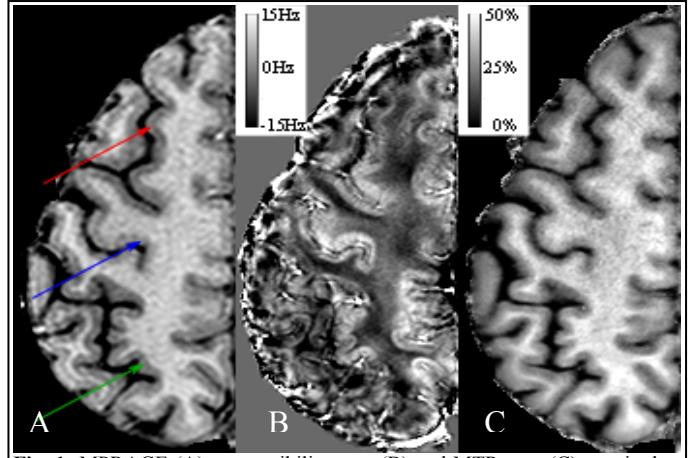


Fig. 1: MPRAGE (A), susceptibility map (B) and MTR map (C) acquired at 7T on a healthy subject. Arrows are respectively designating ROI area in the frontal lobe (red), the motor cortex (blue) and the occipital lobe (green)

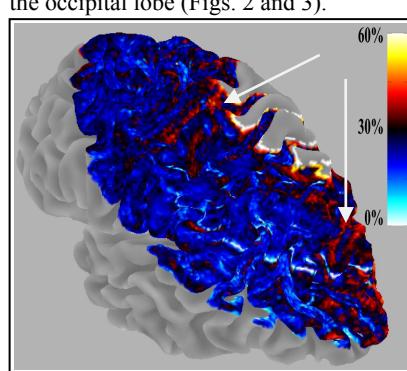
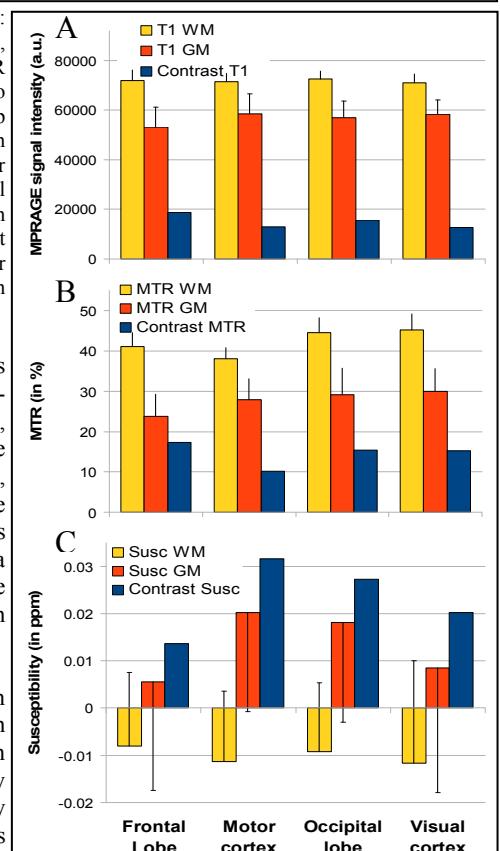


Fig. 3: Mid-cortical surface representation of one subject overlaid with the MTR map. The motor cortex is clearly visible with higher MTR values than the surrounding sulci. Note the elevated MTR value for the occipital and visual cortex (white arrows).

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