Improved characterisation of white matter lesions in multiple sclerosis patients using quantitative susceptibility mapping

Matthew Cronin[1], Samuel Wharton[1], Richard Bowtell[1], and Penny Gowland[1]
[1]*Sir Peter Mansfield Magnetic Resonance Centre, The University of Nottingham, Nottingham, Notts, United Kingdom*

Background: White matter lesions in Multiple Sclerosis (MS) are sometimes surrounded by rings on T2*-weighted magnitude and phase images; it has been suggested that these rings might be a marker of iron [1], but their origin remains a matter of debate. The ability to detect iron changes around lesions would be useful in understanding the pathogenesis of MS lesions and tracking disease progression. There is considerable variation in the appearance of lesions seen on MRI. Here we specifically study lesions with rings that are visible in phase data. It is however difficult to interpret phase images directly since spatial variations in the magnetic susceptibility of tissue cause dipolar fields which result in non-local phase shifts; i.e. the phase map does not directly reflect the underlying susceptibility distribution in the tissue, which could lead to incorrect inferences about the nature and extent of these rings [2]. Quantitative susceptibility mapping (QSM) can be used to address this problem [3].

Aim: To demonstrate (1) the importance of using QSM to study perilesional effects and (2) the relationship between perilesional rings on QSM and signal changes on T2*-weighted images.

Methods: As part of a wider study into grey and white matter lesions, subjects with multiple sclerosis were scanned using a Phillips Achieva 7T system equipped with multi-channel recieve-only head coils, using a multi-stack spoiled 3D GE sequence with 4 overlapping stacks and 0.5mm isotropic resolution (TE =20ms, TR=150ms, FOV =196x164x85mm^3 , EPI factor =3, SENSE factor =2). The phase data for each subject was unwrapped and fields from sources outside of the brain removed using the SHARP method [4]. Quantitative susceptibility maps were generated using an iterative conjugate gradient method [3] limited to 16 iterations. The phase images were examined to find well isolated lesions displaying clear phase rings, and 6 lesions were selected from 4 patients. 1D representations of the white matter (WM) voxel intensity as a function of distance from the lesion edge averaged over all directions were generated based on lesion and white matter masks.

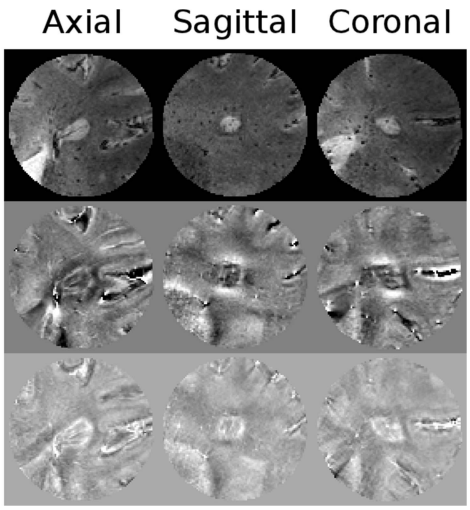

***Fig.1** T2*-weighted magnitude, phase, and susceptibility images of a white matter lesion in a subject with multiple sclerosis.*

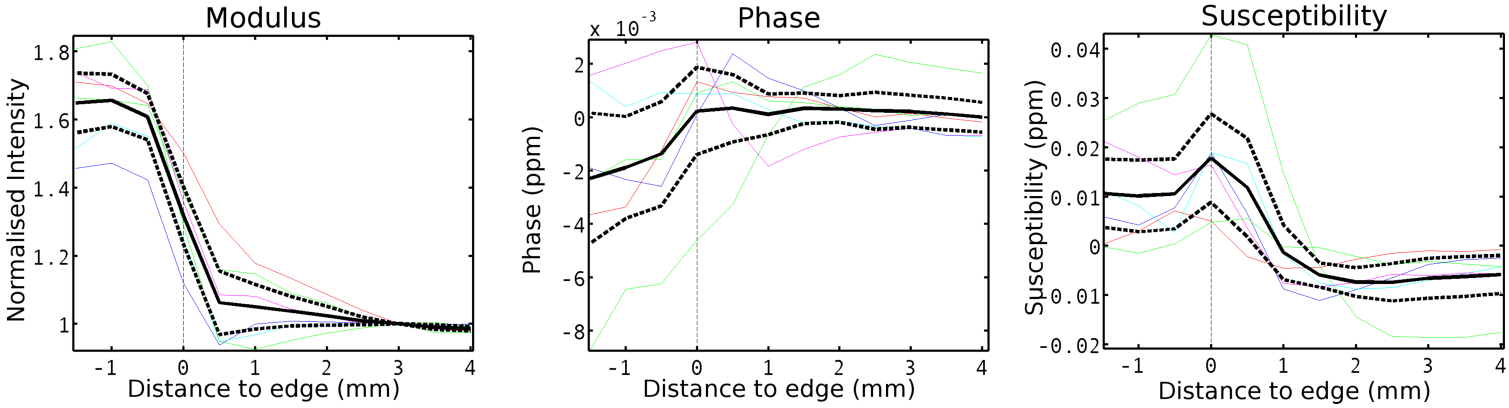

***Fig. 2** Plots of T2*-weighted magnitude, phase and QSM against distance from lesion edge. Coloured lines show individual lesions, solid black lines show the mean and dashed lines show standard deviation over the lesions.*

Results: Figure 1 shows a representative WM lesion in magnitude and phase images, and the resulting QSM image. In the axial plane, the phase image shows a hyper-intense ring at the periphery of the lesion, consistent with the boundary seen in the modulus image, surrounded by a region of hypo-intensity. In the sagittal and coronal planes, the dipolar nature of the phase contrast is more apparent, extending beyond the lesion boundary seen in the magnitude data. This effect also accounts for the hypo-intense region observed in the axial plane. In contrast, the susceptibility maps show hyper-intense rings that are consistent with the lesion boundary in the magnitude images in all 3 planes. Figure 2 shows the radial variation in magnitude signal, phase and susceptibility. The magnitude signal profile is hyperintense inside the lesion, falling monotonically to a flat level in the external WM. The phase profile shows an inconsistent internal intensity, with a slight peak at the lesion boundary. In contrast, the susceptibility profile has a consistent internal hyperintense offset, shows a large peak at the lesion boundary, and falls monotonically to a flat level in the external WM.

Discussion: Recently reported results from histology [5] suggest that the levels of myelin are reduced inside lesions, while iron levels are increased at the lesion boundaries relative to the surrounding WM. In our data, the magnitude profiles show that T_2^* is increased inside the lesion, consistent with myelin loss, but these profiles are relatively insensitive to iron at the lesion boundary. On average the phase profiles increase slightly at the lesion boundary, consistent with increased iron content, but give little, if any, indication of a change in tissue composition internally or externally. This is likely due to the non-local dipolar nature of the phase contrast [4]. In contrast, the susceptibility profile is consistent with an internal loss of myelin (reduced myelin levels lead to a net increase in susceptibility), and an increased level of iron at the lesion edge (increased iron levels produce a positive change in susceptibility) relative to the surrounding WM. In conclusion, QSM provides superior spatial specificity compared to phase images when considering field shifts around MS lesions and also provides image contrast that better reflects the underlying lesion composition compared to either the phase or T2*-weighted magnitude images.

References: *[1] Hammond et al. 2008. Ann. Neurol. (64) 707-713. [2] Schweser et al. 2011. NeuroImage. (14;54(4)) 2789-2807. [3] Wharton and Bowtell. 2010. NeuroImage. (53) 515-525. [4] Schweser et al. 2010. Proc Int Soc Mag Reson Med. (26:4) v5. [5] Bagnato et al. 2011. Brain. (134) 3599-3612*