Application of vector QSM for imaging multiple sclerosis lesions

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TARGET AUDIENCE: Researchers and clinicians interested in multiple sclerosis.

PURPOSE: Quantitative Susceptibility Mapping (QSM) has been applied in imaging patients with multiple sclerosis (MS)(1-2). The MS lesions are often located in white matter regions, where tissue susceptibility is anisotropic(3). In this case, a scalar susceptibility model commonly employed in QSM may be inadequate to account for the anisotropic effect, and a tensor model is needed. However, susceptibility tensor imaging (STI)(3) often requires scanning from multiple orientation, making it unpractical for imaging human subjects.

In this study, we applied a vector QSM method to image MS lesions. The vector QSM fully accounts for the anisotropic susceptibility effect, and only requires a single scan, allowing the detection of spatial changes of susceptibility anisotropy in white matter lesions.

METHODS: *Sample:* The study as approved by IRB. MRI datasets of seven MS patients were retrospectively analyzed. In addition, brain tissue of a MS patient was obtained at autopsy (no disease treatment for this subject, die from cardiac arrhythmia)(4).

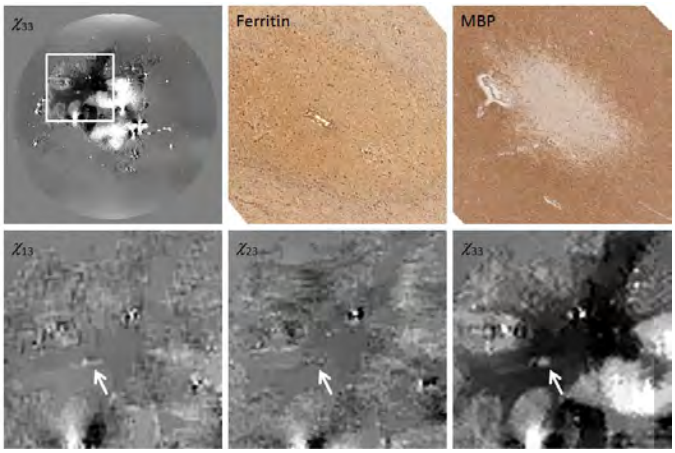

Figure 1. Vector QSM and histology data on a lesion. Immunostaining against ferritin shows a minimal increase in ferritin within the lesion. Immunostaining with antibody against myelin basic protein shows loss of myelin within the lesion.

Imaging: MRI was performed on a 3T GE scanner using a 3D multi-echo gradient echo sequence. Important imaging parameters were as follows: TE/ΔTE/#TE = 4~5ms/4~5ms/11~12; TR=53~58ms; in-plane resolution=0.7x0.7mm^2; slice thickness=0.7~2mm; BW=±62.5kHz. Immunohistochemical labeling was achieved by incubating 10μm sections with primary antibody of myelin basic protein (MBP) to detect demyelination. Perl's staining was also performed to detect Fe^{3+}in ferritin.

Vector QSM: We noticed that in the laboratory frame of reference, only the right most column of susceptibility tensor has contribution to the magnetic field f. Accordingly, the right most column $\{\chi_{13}, \chi_{23}, \chi_{33}\}$ is found by minimizing a regularized fitting:

$$\{\chi_{13}, \chi_{23}, \chi_{33}\}^* = argmin_{\{\chi_{13},\chi_{23},\chi_{33}\}} \left\| W \left\{ f - FT^{-1}\left[\left(-\frac{k_x k_z}{k^2}\right) FT(\chi_{13}) + \left(-\frac{k_y k_z}{k^2}\right) FT(\chi_{23}) + \left(\frac{1}{3} - \frac{k_z^2}{k^2}\right) FT(\chi_{33}) \right] \right\} \right\|_2^2 + \lambda \sum_{i=1}^{3} |M \nabla \chi_{i3}|,$$

where λ is a parameter for regularization, W is noise weighting matrix, and M is edge map derived from magnitude images. The minimization problem was solved using a Newton's method. Scalar QSM were also obtained using the MEDI method (5).

RESULTS: *Brain Tissue:* From Fig. 1, the lesion had little ferritin iron inside the lesion. Demyelination can be recognized in MBP labeled slides with obvious contrast with adjacent normal appearing white matter. On vector QSM, the lesion can be seen on all three components. Lesion showed contrast on the off-diagonal components χ_{13} and χ_{23}, demonstrating spatial changes of susceptibility anisotropy of the lesion.

MS patients: Representative images are shown in Figs. 2. We noticed that a) χ_{33} has improved visual quality compared to QSM; b) signal strength on χ_{13} and χ_{23} is markedly weaker than χ_{33}; c) if a lesion is visible on QSM, it is always visible on χ_{33}. However, not all the lesions are visible on χ_{13} or χ_{23}.

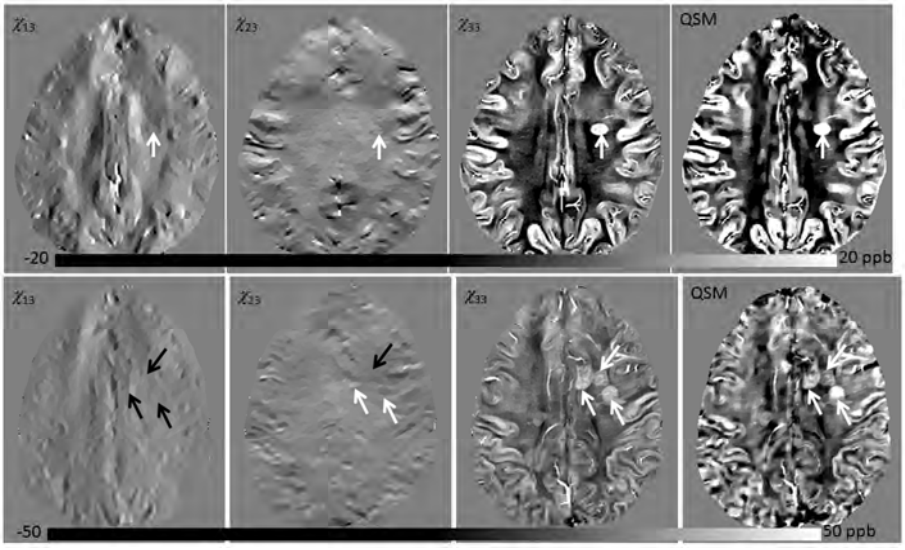

Figure 2. Vector QSM of MS patients. Row 1 and 2 correspond to two patients. White and black arrows are pointing to visible and invisible lesions, respectively.

DISCUSSION: The three components of the vector map have different physical meanings. For isotropic susceptibility sources such as iron, only χ_{33} is expected to have none-zero value. Therefore, χ_{13} and χ_{23} specifically reflects spatial distribution of anisotropic susceptibility sources. This was confirmed in the brain tissue phantom, where disruption of myelin alone (no iron) led to spatial changes of all three components of the vector QSM. However in human brain, some lesions are visible on χ_{33} only, and in general, lesion appearances on χ_{13} and χ_{23} are more subtle than on χ_{33}. This suggests that the lesion susceptibility changes arise primarily from iron instead of demyelination, presumably because iron's susceptibility is much stronger than myelin.

CONCLUSION: Vector QSM improves the image quality of susceptibility mapping, and is able to detect spatial changes of susceptibility anisotropy resulting from demyelination.

REFERENCES: 1.Chen, W *et al*. Radiology 2014;271(1):183-92; 2.Langkammer, C *et al*. Radiology 2013;267(2):551-9; 3.Liu, C. Magn Reson Med 2010;63(6):1471-7; 4.Wisnieff, C *et al*. Magn Reson Med 2014; 5.Liu, T *et al*. Magn Reson Med 2013;69(2):467-76;