Temporal susceptibility variations with multi-echo Quantitative Susceptibility Mapping (QSM)

Sung-Min Gho[1], Yoonho Nam[1], Dongyeob Han[1], and Dong-Hyun Kim[1]
[1]*Electrical and Electronic Engineering, Yonsei University, Seodaemun-gu, Seoul, Korea*

Purpose: Quantitative susceptibility mapping (QSM) methods[1,2] determined from the image phase have been developed for description of tissue anatomy, structure and susceptibility.

MR image and its phase value, however, represent the combined signal of sub-voxel components. In addition, image voxel signal at an echo times (TE) represents signal contributions of various T2 and/or T2* value components. For example, myelin, one of major sub-voxel components in white matter regions, is hard to obtain at long TEs because of its very short T2 relaxation times. A QSM, if determined at different TEs, therefore, would represent different characters even in the same voxels.

We estimated the temporal variations of QSM images at different TEs using multi-echo gradient echo data.

Methods: 1) Data acquisition: In vivo data were collected from 6 healthy volunteers using 3T Siemens Tim Trio MRI scanner. 3D multi-echo gradient echo sequence was applied for obtaining multi-echo QSM data (TR = 120 ms, first TE = 2.1 ms, echo spacing = 1.93 ms, flip angle = 30°, FOV = 256 x 256 mm^2, number of echoes = 20, number of slices = 64, voxel size = 2.0 x 2.0 x 2.0 mm^3) and diffusion tensor imaging (DTI) was also obtained (TR = 9700 ms, TE = 92 ms, b-value = 600 sec/mm^2, number of diffusion encoding directions = 64, number of slices = 64, voxel size = 2.0 x 2.0 x 2.0 mm^3) for comparing the diffusion fractional anisotropy (FA) with the temporal susceptibility variations.

2) Data processing: We used PRELUDE for phase unwrapping[3], projection onto dipole fields method to remove the background phase[4] and applied a L1 norm regularization method to reconstruct QSM images[2]. Reconstructed QSM images were registered using MNI templates in FSL and averaged over all volunteers for each echo. A mono-exponential fitting of the QSM values defined as: $y = e^{A \cdot TE_i} + B$ (where A is time constant, B is DC term, and TE_i represents i^{th} TE) was applied for estimating each voxel's temporal susceptibility variations. A temporal susceptibility coefficient map (TSM) was generated by mapping the time constant determined from each voxel. Correlation of the TSM with known myelin water fraction (MWF) was also calculated. All data reconstruction was performed using MATLAB R2009b.

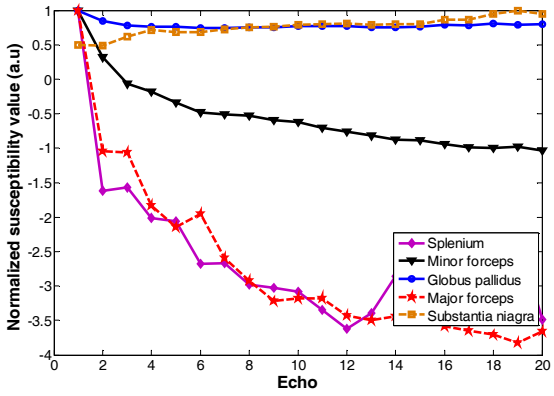

Figure 1: normalized temporal susceptibility variations of several regions

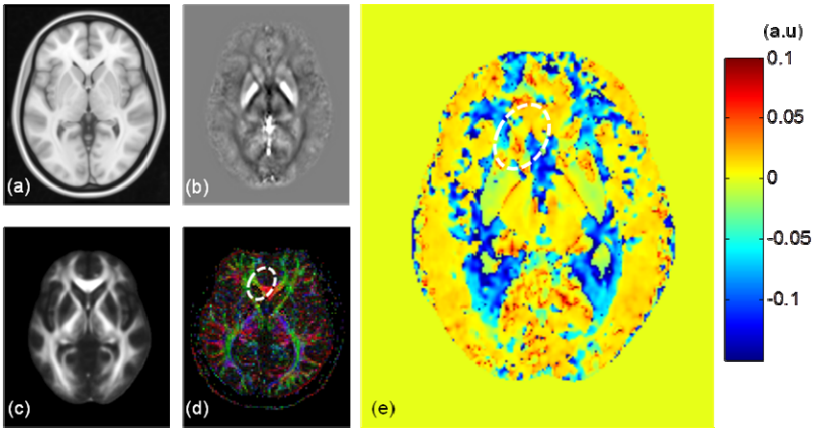

Figure 2: (a) MNI template, (b) averaged QSM at 10th echo, (c) DTI FA template, (d) color coded FA map, and (e) proposed temporal susceptibility coefficient map (TSM).

Results: The normalized temporal QSM variations of several regions are shown in Fig. 1. Most variations of the susceptibility values happened at early echoes (1st ~ 10th echo). The globus pallidus (GP) and substantia niagra (SN) that are high iron concentration regions represent little variations compare to most myelin rich regions such as minor forceps (mF), major forceps (MF), and splenium (SP). Fig. 2 shows the reference MNI template, the averaged QSM at 10th echo over all subjects, the DTI FA template and its color coded FA map of one volunteer, and the proposed TSM. In TSM, the red color represent increase of susceptibility values and blue color represent decrease of susceptibility values as echo time increases. Most susceptibility value of white matter regions show clear decrease, the GP has little variations, and cortical gray matter (GM) regions show increasing feature. Compared to color coded DTI FA map, clear correlations are shown in the regions of green color coded (Anterior-Posterior direction fibers) white matter regions.

Fig.3 plots the measured temporal susceptibility coefficients of several regions (SP, mF, MF, cortical GM) with previously reported MWF vaules[5]. A strong correlation is observed (correlation coefficient (R) = -0.89).

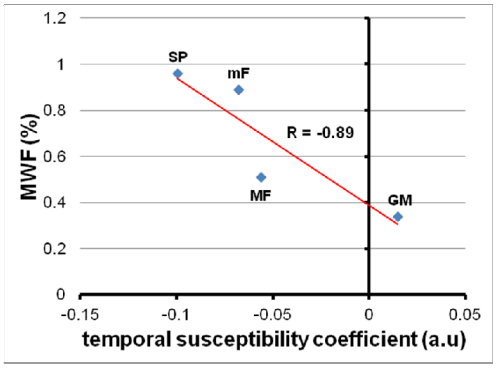

Figure 3: measured temporal susceptibility coefficients against reported MWF.

Discussion: It has already been reported that the measured susceptibility values in a voxel with dominant susceptibility factors such as calcification show consistent result independent of TE[6]. Our results also show consistent QSM in high iron deposition regions (i.e. GP and SN in Fig. 1). However, other regions show noticeable variations, especially at early echoes. Estimating MWF using multi-gradient echo images (i.e. T2* decaying) is known to have artifacts in high iron deposition regions such as GP induced by the T2* shortening from susceptibility effects[7]. Our proposed method, however, may have potential to represent myelin components without these artifacts. Moreover, TSM shows discontinuities at some white matter regions compared to FA (dotted ellipsoids in Fig. 2. (d) and (e)) which may be related to white matter anisotropy and/or fiber orientations. Further studies need to validate these assumptions.

Acknowledgements: MKE and KIAT through the Workforce Development Program in Strategic Technology. NRF grant funded by the MEST (No. 2012-009903).

References: 1. Liu T, et al. MRM 2009;61:196-204, 2. Bilgic B, et al. NeuroImage 2012; 59:2625-2635, 3. Jenkinson M. MRM 2003;49:193-197, 4. Liu T, et al. NMR in Biomedicine 2011; 24:1129-1136, 5. Whittall K, et al. MRM 1997;37:34-43, 6. Liu T, et al. Radiology 2012;262:269-278, 7. Hwang D, et al. NeuroImage 2010;52:198-204.