Resolution improvement in Quantitative Susceptibility Mapping by denser sampling of spatial dipole field

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Introduction: Quantitative Susceptibility Mapping (QSM) provides a distribution of tissue magnetic susceptibility. A high resolution mapping of susceptibility distribution could pave a way to attain early diagnosis of neurodegenerative disease. Susceptibility distribution is calculated by deconvolving a perturbed field with a spatial unit dipole field. Since the dipole field becomes larger near the origin and changes in the sign, it has a rapid changing nature. Thereby, a digitally sampled dipole field brings susceptibility estimation errors.[1,2] However, a dipole field can be calculated exactly in a very fine scale. In this study, we performed numerical simulations taking into account partial volume effects, and aimed to improve spatial resolution of QSM by denser sampling of the dipole field.

Fig1:Shepp-Loganphantom$(3 \times M)^3$,χ_1 :0.3ppm, $\chi_{2,3}$:0.2ppm, χ_4 :0.4ppm, χ_5 :0.1ppm, $\chi_{6,7,8,9,10}$:0.5ppm, shell:1.0ppm, Background:0ppm

Fig2:Shepp-Logan phantom $(M)^3$, Background field was removed

Methods: From input perturbed field whose matrix size was $(M)^3$, we calculated a susceptibility map $(3 \times M)^3$.

Perturbed field including partial volume effects: A perturbed field with high spatial resolution was created from high resolutional 3D Shepp-Logan phantom and was downscaled to have partial volume effect.[1,2] In this study, an analytically Fourier-transformed dipole field was employed.[3] The matrix size of an input perturbed field including partial volume effects was $(24)^3$. To evaluate spatial resolution, we added structures whose susceptibility values (χ_i) were 0.5 ppm to the phantom.

Susceptibility estimation: Back ground field was removed, by using the SHARP method.[4] Since our numerical phantom had no susceptibility anisotropy, we employed COSMOS[5] to calculate susceptibility distribution. Three angles, -60°, 0° and 60°, were used, and the inverse problem was solved in Fourier domain. In this study, Fourier-transformed dipole field was set to zero in regions where the absolute values of dipole field were less than 0.14, and susceptibility maps were formed after weighting the value of susceptibility distribution by the absolute value of dipole fields for each orientation so that each measurement made an equal contribution.[3]

Data preparing: Two data sets were created to calculate larger size of the susceptibility maps $(3 \times M)^3$. In the proposed method, from input perturbed field $(M)^3$, large matrix size perturbed field $(3 \times M)^3$ was created by expanding to three times the input perturbed field. We employed the nearest neighbor algorithm to expand because it could avoid smoothing and maintain rapid changes of the field. Then, denser sampled dipole field $(3 \times M)^3$ was created analytically. In the conventional method, perturbed field size and dipole field size were $(M)^3$. Susceptibility map $(M)^3$ was calculated and interpolated to three times by the bicubic method.

Fig3:The result susceptibility maps. Blue lines correspond to the profiles in Fig4

Fig4:Susceptibility profiles of the two result maps at blue lines in Fig3

Results and Discussion: The susceptibility map $(3 \times M)^3$ in the Shepp-Logan configuration is shown in Fig1. Figure1 corresponds to the answer of susceptibility estimation in high resolution. A low resolution susceptibility map $(M)^3$ is shown in Fig2. The calculated susceptibility distributions are shown in Fig3. In the result of Proposed method, regions of χ_4, χ_7, χ_8 and χ_9 are clearly distinguishable, while in the result of Conventional method, they merge with surroundings. Although the regions of χ_6 are distinguishable in both, their shapes are different. In the result of Proposed method, the region of χ_6 has a spherical shape as Fig1, while in the result of Conventional method, the region of χ_6 has a rectangle one. Susceptibility profiles of the two result maps at z=37, y=42 are shown in Fig4. In Proposed method of Fig4, regions of χ_2, χ_3 and χ_7 are separated from surroundings, while in Conventional method the region of χ_7 merges with χ_2 and χ_3. However, both methods could not restore susceptibility values of small regions with higher suceptibility. This may be caused by that high frequency variation of susceptibility is smeared out in a measured perturbed field map as in Fig2.

Conclusion: Susceptibility maps with higher spatial resolution is obtained by employing a denser sampled dipole field and expanding a measured perturbed field.

References: 1: Murashima. M et al. EMBC Conf Proc. (2013) 1049-1052. 2: Murashima. M et al. ISMRM Conf Proc. (2013) 2481. 3: Wharton. S et al. MRM 63 (2010) 1292-1304. 4: Schweser. F et al. NeuroImage 54 (2011) 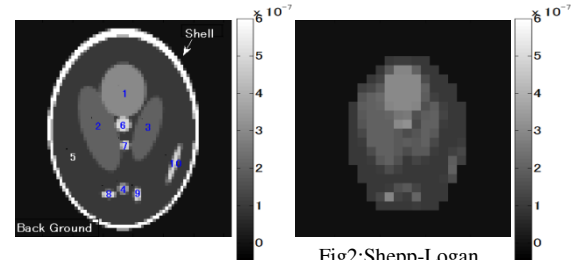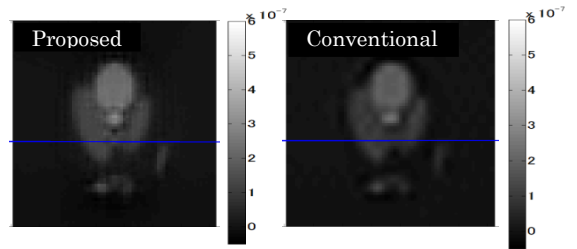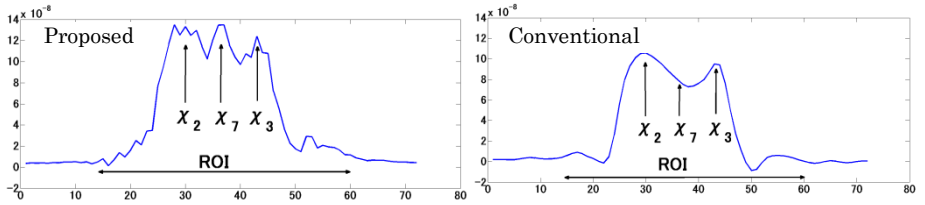2789-2807. 5: Liu. T et al. MRM 61 (2009) 196-204.