A comparison of T2* magnitude, SWI, k-division susceptibility map, Maxwell equation regularized quantitative susceptibility map for brain iron mapping

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Introduction: Magnetic susceptibility is a new type of MR tissue contrast obtained from the phase information of gradient multi-echo MR images and gives new information about susceptibility sources including iron-deposition and calcifications that may assist diagnosis of neurodegenerative diseases and cerebral microbleeds [1-2]. This information is distinct from susceptibility weighted imaging (SWI), a T2* magnitude image multiplied by a phase mask generated by a linear ramp for negative magnetic field deviations raised to the 4th power [3]. To obtain a true map of susceptibility sources, the phase information must be used to first reconstruct the local B-field. Then it is used to solve the inverse problem of the susceptibility sources that caused B-field distortions. The inverse problem is ill-posed, since the magnetic dipole convolution kernel has zeros at an angle of 55° relative to the main field. However, solutions to the problem arise by either sampling at multiple orientations [1], zero-filling the ill-conditioned k-space frequencies prior to k-space division with the dipole convolution kernel [4], or by regularizing the inverse problem with prior information with a method called quantitative susceptibility mapping (QSM) [2]. Note that while T2* images fundamentally measure the total variation of the local B-field within individual voxels from detecting transverse dephasing, QSM and truncated k-division are derived from the magnetic field map, which independently measures the average phase of a voxel. Herein we compare QSM, SWI, and truncated k-division in patient data.

Methods: The QSM reconstruction method consists of regularizing the ill-posed inverse problem by minimizing $\|W_G G \chi\|_1$ that is a Maxwell Equation derived sparsity term, while requiring that $\|W (D \chi - b)\|_2 < \varepsilon$ where χ is the spatial distribution of the susceptibility that we are solving for; b is the measured magnetic field map after phase unwrapping and removal of background sources through effective dipole fitting; D is the known convolution kernel of the dipole field; G is the gradient operator that regularizes the problem by promoting sparsity; ε is a adjustable parameter to enforce consistency; W is a weighting matrix based on the noise in the phase data; and W_G is a weighting matrix based on the gradients of the T2* image where large gradients in the T2* image are set to zero so the minimization of $\|G \chi\|_1$ does not penalize for the corresponding large gradients in the susceptibility map.

MR images were acquired from five subjects at 3T (Signa 15.0 GE) using a gradient multi-echo SWAN sequence of the entire brain using the 8-channel GE head coil. Subjects had no common underlying disease conditions. The pulse sequence is a unipolar train of 5 echos with the first echo at TE=3.7ms and a constant echo spacing =3.7ms, TR=33.7ms, FA= 20°, and BW=31.25x2 kHz. All reconstruction methods used the same raw field map generated from the multi-echo phase information after phase unwrapping and removing the background fields using effective dipole fitting from sources outside the brain. ROIs were defined for the pallidum, substantia nigra, red nuclei, putamen, and cerebral microbleeds to compare between the two quantitative methods (QSM and truncated k-division).

Results: The QSM method produced superior results compared to truncated k-division, which introduced noise artifacts and consistently underestimated the susceptibility by 10-30% in ROIs compared to the QSM (Figure 1a). This is expected as the abrupt truncation of the convolution kernel either loses information contributing to susceptibility signal or amplifies noise due to the ill-conditioning, whereas the regularized QSM method incorporates all the measured phase data buy weighting the information with the expected noise. QSM is complimentary to and independent of SWI, since the QSM images represent a weighted inversion of a convolution of the measured field deviations with the dipole kernel, so QSM calculates the location of the susceptibility sources whereas SWI provides a phase mask of the original field map over the original T2* image.

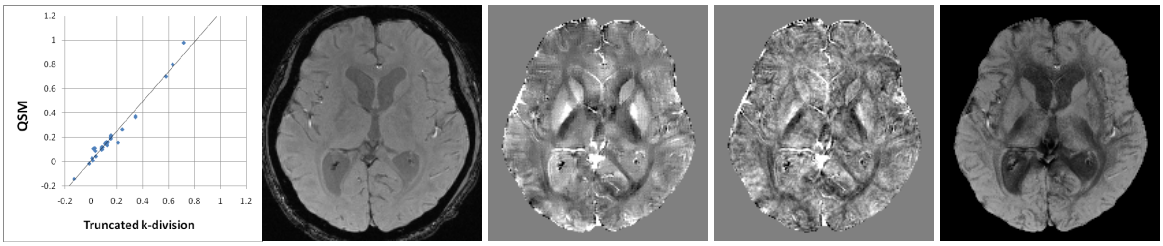

Figure 1: From left to right: (a) plot of means of identical ROI's from five patients in k-division and QSM showing a slope of 1.22 indicating 22% underestimation by truncated k-division; (b) the original T2*; (c) QSM; (d) truncated k-division; and (e) SWI.

References [1] Liu et al. MRM:61:196-204; [2] de Rochefort et al. MRM: *in press*; [3] Haacke et al AJNR:30:19-30; [4] Shmueli et al. MRM:62