Simultaneous Quantitative Imaging method for Neuroimaging

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Target Audience: Researchers who are interested in simultaneous quantitative imaging of conductivity mapping (QCM), QSM, R_2*, and R_2' mapping.

Introduction: MR imaging can provide various quantitative information regarding the electro-magnetic properties and relaxation properties of tissue (ex. conductivity, susceptibility, R_2* and R_2'). The electric and magnetic properties are linked through Maxwell's equations and the magnetic susceptibility is one major source of the R_2* and R_2'. These four quantitative information, therefore, are closely related. Although these quantitative information can be used independently, studies which utilize several of these related quantitative information together can alleviate limiting factors such as mis-registration, different physiological noise and lengthened scan time due to separate measurements. Previous reports have shown that conductivity can be obtained using the spin echo (SE) phase values[1,2]. Susceptibility, on the other hand, can be measured via the phase evolution obtained after TE = 0 (i.e. TE > 0) using gradient echo (GRE) sequences[3,4]. Also, R_2* and R_2' can be acquired simultaneously using refocusing pulse with multiple GREs[5,6]. In this abstract, we propose a new method for obtaining these four quantitative applications simultaneously and validate the measured values using the previous reports.

Materials and Methods

1) Data acquisition: In vivo data were collected from healthy volunteers using 3T Siemens Tim Trio MRI scanner. A 3D SE with multiple GRE sequence (Fig 1) was applied (TR = 700 ms, first TE = 15 ms, first TE in section B = 21 ms, first TE in section C = 82 ms, echo spacing = 6 ms, FOV = 256 x 256 mm^2, number of echoes in section B &C = 6, number of slices = 12, voxel size = 1.0 x 1.0 x 2.0 mm^3, scan time = 35 min 50 sec).

2) Data processing

·QCM: For conductivity mapping, we employed phase-based electric properties tomography using the SE phase i.e. first echo data (section A)[1,2]. A weighted polynomial fitting technique was applied to calculate the second order spatial derivative of phase. After polynomial fitting, bilateral filtering was applied.

·QSM: Using the GRE phases in the section B, the Laplacian unwrapping method was utilized for phase unwrapping[3], projection onto dipole fields method was used to remove the background phase[7] and the morphology enabled dipole inversion method was applied to reconstruct QSM images[8,9].

·R_2* and R_2' mapping: We assumed a mono-exponential decay model with the Levenberg-Marquardt analysis algorithm using the MR signal $S(t)$. The estimated R_2* from the section B and R_2' from section B & C can be described by,

$$S(t) = \begin{cases} S_{0,B} \exp\left(-R^*_{2,B} t\right) \\ S_{0,C} \exp\left(-R^*_{2,C} t\right) \end{cases}, \quad R'_2 = \left(R^*_{2,B} - R^*_{2,C}\right)/2$$

Results & Discussion: Fig 2 represents the reconstructed magnitude images and estimated QCM, QSM, R_2*, and R_2' maps. Measured quantitative values in several region of interests (ROIs) are listed in Table 1. These estimated values were in good agreement with literature values of previous studies[9-12].

One limitation of this method is the relatively long scan time. Applying fast imaging methods such as parallel imaging and compressed sensing can be helpful. Flow compensation gradients were not used in our proposed method, this can induce quantification errors in flow related regions.

Conclusion: A method for simultaneous imaging of quantitative conductivity and susceptibility related constants is proposed. The method can be useful for understanding the underpinnings of the in vivo brain in relationship with the electro-magnetic properties. The method can also be useful for clinical applications where these properties are known to change, such as tumors, hemorrhages, and strokes.

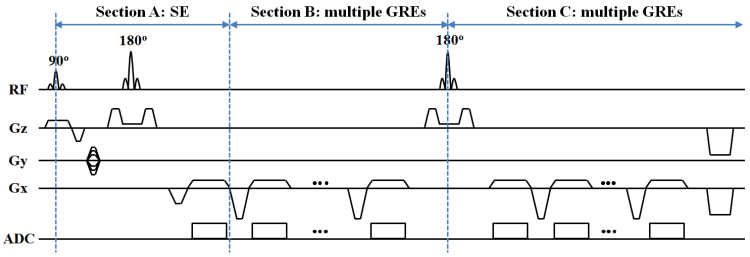

Figure 1: Proposed pulse sequence diagram. Section A: SE data was obtained for QCM reconstruction. Section B: multiple GRE data were acquired for QSM and R_2* mapping. Section C: additional multiple GRE data were obtained for estimating R2' mapping.

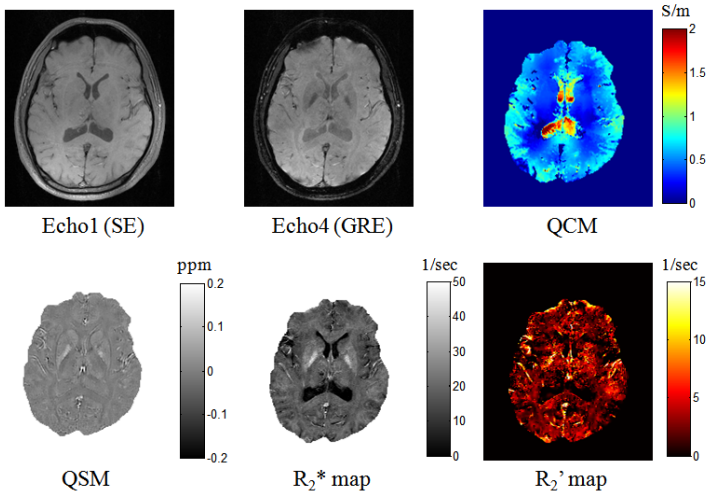

Figure 2: In vivo reconstructed images of the proposed method.

Table 1. Estimated quantitative values.

ROI	QCM	R_2'	ROI	QSM	R_2*
CSF	1.96 ± 0.37 (2.09 ± 0.12)	-	Globus Pallidus	0.183 ± 0.041 (0.187 ± 0.017)	38.83 ± 4.99 (35.47 ± 3.3)
GM	0.56 ± 0.07 (0.52 ± 0.06)	2.75 ± 1.96 (2.7 ± 2.4)	Putamen	0.072 ± 0.020 (0.086 ± 0.041)	24.44 ± 1.69 (25.06 ± 2.2)
WM	0.34 ± 0.04 (0.30 ± 0.03)	3.75 ± 1.80 (3.7 ± 1.6)	Caudate	0.082 ± 0.010 (0.080 ± 0.020)	-

(): literature values of previous studies.

References: [1] U Katscher et al. IEEE TMI 2009,28:1365-1374 [2] T Voigt et al. MRM 2011,66:456-466 [3] W Li et al. NeuroImage 2011,55:1645-1656 [4] T Liu et al. MRM 2009,61:196-204 [5] J Ma et al. JMR 1997,125:92-101 [6] D Yablonskiy et al. MRM 1997,37:872-876 [7] T Liu et al. NMR in Biomedicine 2011,24:1129-1136 [8] L Rochefort et al. MRM 2009,63:194-206 [9] T Liu et al. MRM 2011,66:777-783 [10] T Voigt et al. MRM 2011,66:456-466 [11] W Ni et al. MRM 2014, E-pub [12] P Peran et al. JMRI 2007,26:1413-1420