Simultaneous Imaging of Conductivity and Susceptibility using double-echo UTE sequence

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Introduction: MR imaging can provide information regarding the electric and magnetic properties of tissue (i.e. conductivity, and susceptibility). Various studies using these electrical conductivity and magnetic susceptibility properties were performed independently[1,2]. Being able to simultaneously quantify both conductivity and susceptibility mapping can be useful since mis-registration can be alleviated due to separate measurements. Previous reports have shown that conductivity can be obtained using phase values obtained at TE = 0[3]. Susceptibility, on the other hand, can be measured via the phase evolution obtained after TE = 0 (i.e. TE > 0) using gradient echo sequences. Recently, new methods for conductivity and/or susceptibility imaging such as simultaneous conductivity and susceptibility imaging[4] were developed, along with new techniques for conductivity mapping using ultrashort echo time (UTE) imaging[5], and short TE quantitative susceptibility mapping (QSM)[6].

In this abstract, we propose a new method for performing these three recent applications simultaneously using a double-echo UTE sequence. From the first echo data, we acquired conductivity maps and short TE QSM, and from the second echo data, QSM was obtained.

Materials and Methods

1) Data acquisition: In vivo data were collected from healthy volunteers using 3T Siemens Tim Trio MRI scanner with a single-channel Tx/Rx birdcage coil. A 3D pointwise encoding time reduction with radial acquisition (PETRA) sequence[7] was applied (TR = 30 ms, first TE = 0.06 ms, second TE = 15 ms, flip angle = 15°, FOV = 256 x 256 mm^2, number of slices = 256, number of spokes = 50000, voxel size = 1.0 x 1.0 x 1.0 mm^3, scan time = 23 min 43 sec).

2) Data processing

·QCM (Conductivity mapping): For conductivity mapping, we employed phase-based electric properties tomography (EPT) using the UTE phase i.e. first echo data which has a TE of 60 us. A 3D weighted polynomial fitting technique was applied to calculate the second order spatial derivative of phase. Magnitude image at second echo was used to produce weighting factors for polynomial fitting[8].

·QSM: We used Laplacian unwrapping method for phase unwrapping[9], projection onto dipole fields method to remove the background phase[10] and applied a L1 norm regularization method to reconstruct QSM images[11] at the second echo data. The RF induced phase (often called the B_1 phase) effects on QSM were removed by subtraction of a six-order 3D polynomial fitted UTE phase (i.e. we assumed UTE phase as the B_1 phase). The effects of the presence of B_1 phase on QSM were investigated by performing QSM with and without B_1 phase removal.

·UTE QSM: The B_1 phase values were retrieved by using a linear extrapolation of the double-echo unwrapped phase data and subtracted from UTE phase for removing B_1 phase effects. Similar QSM procedure was performed for UTE QSM.

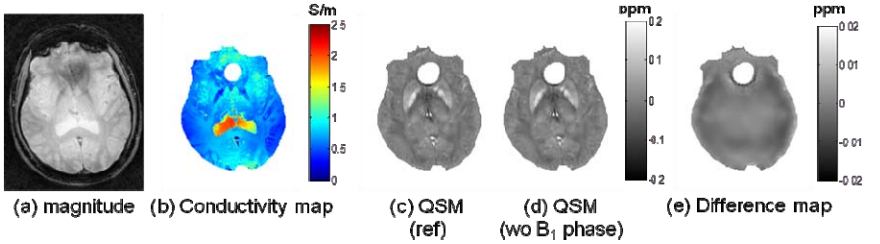

Figure 1: Reconstructed in vivo images. (a) magnitude image, (b) QCM, (c) QSM without removing the B_1 phase, (d) QSM with removing the B_1 phase, (e) difference image between the (c) and (d)

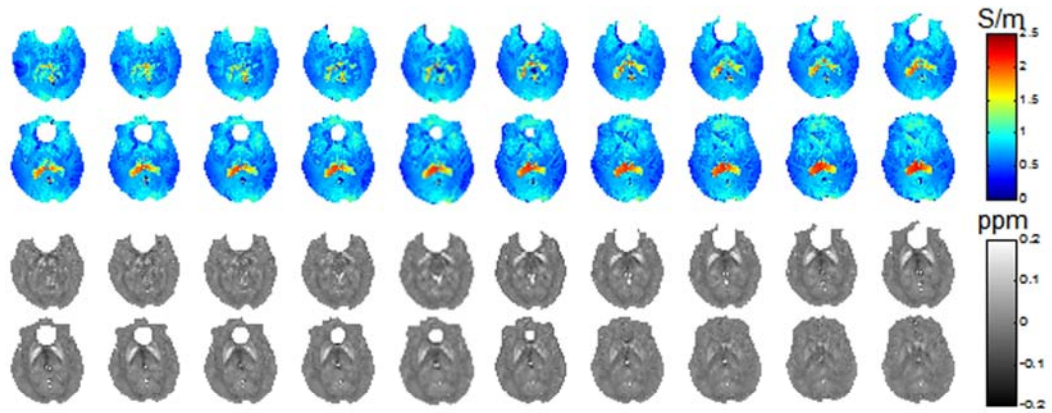

Figure 2: successive 20 slices from the reconstructed QCM and QSM.

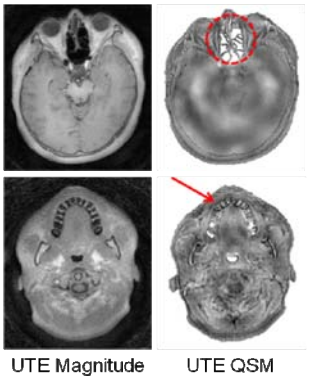

Figure 3: UTE magnitude images (left) and corresponding QSMs (right).

Results & Discussion: Fig 1 represents the reconstructed magnitude image and corresponding QCM and QSMs. Reconstructed QSM at the second echo with and without B_1 phase removal are shown. There is a slight difference between reconstructed QSM with and without B_1 phase removal due to relatively long echo time[4]. In Fig 2, the whole brain QCM and QSM of a healthy volunteer are shown. Estimated conductivity values were 2.17 ± 0.27 S/m in the cerebral spinal fluid (CSF) and 0.69 ± 0.16 S/m in the white matter (WM). These conductivity values were in good agreement with literature values of approximately 2 S/m for CSF and 0.6 S/m for WM tissue[12] and previous study using UTE imaging[5]. We assumed the UTE phase as the B_1 phase for QCM reconstruction, however, this assumption is not valid in B_0 inhomogeneity sensitive regions such as frontal lobe and induces signal loss and severe phase wrapping (Fig 1 and 2). Improved shimming methods mitigate these limitations and enhance the SNR.

An added feature of using the approach is shown in Fig 3. The results show good delineation of the some tissues and teeth (a dotted circle and arrow), which are usually not detectable in the general QSM images due to their short T2* values.

Conclusion: A method for simultaneous mapping of conductivity and susceptibility is proposed. A dual echo acquisition method is used which is insensitive to mis-registration of the two information. 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 tumor, calcifications, iron etc.

References: 1. U Katscher et al. IEEE TMI 2009,28:1365-1374. 2. L de Rochefort et al. MRM 2008,60:1003-1009. 3. T Voigt et al. MRM 2011,66:456-66. 4. DH Kim et al. MRM 2013, E-pub. 5. F Schweser et al. ISMRM 2013, p.4190. 6. S Buch et al. ISMRM 2013, p.2483. 7. DM Grodzki et al. MRM 2012,67:510-518. 8. U Katscher et al. ISMRM 2012, p.3482. 9. W Li et al. NeuroImage 2011,55:1645-1656. 10. T Liu et al. NMR in Biomedicine 2011,24:1129-1136. 11. B Bilgic et al. NeuroImage 2012,59:2625-2635. 12. S Gabriel et al. Phys Med Biol 1996,41:2271-2293.