MAGNETIC RESONANCE ELECTRICAL PROPERTIES TOMOGRAPHY (MREPT) BASED ON THE SOLUTION OF THE CONVECTION-REACTION EQUATION

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Introduction: Imaging of electrical properties (EP) of tissues (conductivity $\sigma$ and permittivity $\varepsilon$) using MRI is important to provide diagnostic information about tissues and patient-specific real-time SAR calculation. Magnetic Resonance Electrical Properties Tomography (MREPT) achieves noninvasive electrical property mapping using the measured complex $B_1^* \hat{f}$ field at Larmor frequency. Currently available practical MREPT methods reconstruct electrical properties within local homogeneous regions where $\sigma$ and $\varepsilon$ values are almost constant. In this study, we propose a novel algorithm named convection-reaction equation based MREPT (cr-MREPT) which reconstructs $\sigma$ and $\varepsilon$ also in transition regions where $\sigma$ and $\varepsilon$ vary. A similar algorithm has been previously proposed for MREPT1.

Theory: Starting from the Maxwell’s equations, a partial differential equation (Eq. 2) is derived for $\gamma = \sigma + iw\varepsilon$. For birdcage and TEM coils, it is reasonable to neglect the axial $H_z$ component and using this assumption, Eq. 3 is derived. Dividing by $\gamma$ and defining $u=\gamma/\gamma$, we obtain Eq.4 which is in the form of the convection-reaction equation where the coefficients depend on the complex $B_1^*$ map.

Method: Simulated magnetic field data is generated using COMSOL Multiphysics (COMSOL AB, Sweden) for the phantom shown in Fig.1a. In this phantom two eccentric cylindrical objects with different EPs are placed in a birdcage coil model. The cross-sectional $\sigma$ and $\varepsilon$ distributions are shown in Fig. 1b. For experimental studies, we constructed a rectangular phantom (filled with solution of 1 gr/l CuSO$_4$, 12 gr/l NaCl, $\sigma$ measured as 1 S/m) which contains a cylindrical bottle (filled with solution of 1 gr/l CuSO$_4$, 2.3 gr/l NaCl, $\sigma$ measured as 0.4 S/m). All experiments were performed on a 3T MR scanner (Siemens, Erlangen, Germany) using quadrature transmit/receive coil. $B_1^*$ amplitude map is acquired using double angle method (flip angle = 45° and 90°, TR=2000ms, GRE, 1.6x1.6x5mm, 3 axial slices). In simulations and experiments, Laplacian of $B_1^*$ is calculated using 3 axial slices. A Gaussian filter with kernel size 5 and standard deviation 1 is applied to the measured complex $B_1^*$ maps. Using simulated and measured $B_1^*$ magnitude and phase maps, convection-reaction equation (Eq.4) is then solved using finite element method (FEM) to reconstruct $\sigma$ and $\varepsilon$ as shown in Fig.1c and 2c, 2d. In these figures, a spot-like artifact is observed. This artifact is mainly due to the numerical errors introduced by the region where the modulus of the convective field is very small.

Results: Using simulated $B_1^*$ map, the solution of Eq.4 gives the $\sigma$ and $\varepsilon$ reconstructions shown in Fig.2a and 2b. In these figures, a spot-like artifact is observed. This artifact is mainly due to the numerical errors introduced by the region where the modulus of the convective field is very small. However, after applying a Gaussian filter, the spot-like artifact is reduced as shown in Fig.2c and 2d. Using experimentally obtained $B_1^*$ map, $\sigma$ is reconstructed using three different methods as shown in Fig.3d-3f: (i) Eq.4 is solved directly in which case the spot-like artifact is again observed. (ii) Eq.4 is solved providing a-priori knowledge in the LCF region and thus the spot-like artifact is eliminated. (iii) Eq.5 is used in all regions (Wen’s method) and reconstruction errors are significantly large around the boundary of the bottle where $\sigma$ changes.

Discussion and Conclusion: Using both the simulated and the experimental data, reconstructions using cr-MREPT are successful in all regions, including the $\sigma$ and $\varepsilon$ transition regions. Since Laplacian operation amplifies noise, cr-MREPT method is sensitive to noise and the quality of reconstruction results depends on the number of $B_1^*$ complex maps. We are currently working on decreasing the noise effect on reconstructions and on increasing SNR of $B_1^*$ maps. In addition, in order to eliminate spot-like artifacts, we are working on acquiring multiple sets of $B_1^*$ data with different LCF regions and combining them while solving Eq.4.

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