

CR-MREPT USING MULTICHANNEL RECEIVE COIL

Necip Gurler¹, Omer Faruk Oran¹, and Yusuf Ziya Ider¹

¹Electrical and Electronics Engineering, Bilkent University, Ankara, Ankara, Turkey

Introduction: Imaging of electrical properties (EPs, conductivity σ and permittivity ϵ) of tissues has importance for diagnostic information and local SAR calculation. Magnetic Resonance Electrical Properties Tomography (MREPT) provides EP images of tissues noninvasively using the measured RF magnetic field (B_l). Standard MREPT (std-MREPT) methods¹⁻³ find the EPs only in regions where electrical properties vary slowly. Recently Sodickson et al.⁴ have proposed the use of multi coil configurations to solve this problem. To calculate the EPs of tissues everywhere in the region of interest (ROI) including the transition regions, our group has proposed a method called convection reaction equation based MREPT (cr-MREPT)⁵. In this method, a partial differential equation (PDE) which is in the form of convection-reaction equation is derived for admittance, $\gamma = \sigma + i\omega\epsilon$. The coefficients of the PDE depend on $B_l^{(+)}$, left handed rotating RF magnetic field, and its first and second derivatives. Later, in another study, we have proposed multi excitation cr-MREPT based on padding⁶. In this study, we propose multi receive cr-MREPT using a standard MRI coil configuration: quadrature body coil (transmit) and multi channel receive only phased array head coil.

Theory: Since multi channel receive array is used in this study, we have derived a convection-reaction PDE (Eq. 1), for $u=1/\gamma$, the coefficients of which depend on $B_l^{(-)}$, right handed rotating RF magnetic field. In this equation, $\partial u/\partial z$ is assumed to be negligible and \mathbf{F} is called the convective field.

$$\mathbf{F} \cdot \bar{\nabla} u + \nabla^2 B_l^{(-)*} u - i\omega\mu_0 B_l^{(-)*} = 0, \text{ where } \mathbf{F} = \begin{bmatrix} \partial B_l^{(-)*}/\partial x + i\partial B_l^{(-)*}/\partial y \\ -i\partial B_l^{(-)*}/\partial x + \partial B_l^{(-)*}/\partial y \end{bmatrix} \text{ and } \bar{\nabla} u = \begin{bmatrix} \partial u/\partial x \\ \partial u/\partial y \end{bmatrix} \quad (1)$$

To solve Eq. (1), we need to know $B_l^{(-)}$ and its first and second derivatives. Magnitude of the MR received signal ($|S|$) can be written as $|S|=|M^+||B_l^{(-)*}|$ where $|M^+|$ is the magnitude of the transverse magnetization and can be defined as $|M^+|=M_0\sin(\gamma_g t)|B_l^{(+)}|$ ⁷. When transmit/receive quadrature birdcage coil is used, magnitude of MR received signal can be rewritten as $|S|\approx|M^+||B_l^{(+)}|$. Since $|B_l^{(+)}|$ can be mapped using a B_1 mapping technique, $|M^+|$ can be found using the equation $|M^+|=|S_{BC}|/|B_l^{(+)}|$. If we transmit from the same birdcage coil and receive the MR signal from different coil, for example multi channel phased array head coil, we can find the $|B_l^{(-)*}|$ of each receive channel, denoted by i , using the equation $|B_l^{(-)*}|=|S_i|/|M^+|$. To find the phase of $B_l^{(-)*}$, we first calculate the transmit phase based on the assumption that $B_l^{(+)}$ phase is half of the spin-echo MR phase image when quadrature birdcage coil is used. Then subtracting this transmit phase from the MR received signal phase, one can obtain the receive phase for each channel as $\phi_i^{(-)*}=\phi_{Si}-\phi^{(+)}$.

Methods: For the simulations, RF magnetic field data is generated using COMSOL Multiphysics[®] (COMSOL AB, Sweden). In Fig. 1a, geometric model of the simulation phantom which consists of three anomaly objects (shown as red, $\sigma=1.2$ S/m and $\epsilon_r=76$), the background region (shown as purple, $\sigma=0.45$ S/m and $\epsilon_r=77$), and a rectangular shaped surface coil are shown. By rotating the coil and redoing the simulation, different RF magnetic field data corresponding to the different coil positions can be obtained. For the experimental studies, the background region is made by using agar-saline solution (20 gr/l Agar, 2 gr/l NaCl, 1.5 gr/l CuSO₄) and the anomaly objects is filled with a saline solution (8.8 gr/l NaCl, 1.5 gr/l CuSO₄) after the background region is solidified. All experiments were performed on a 3T MR scanner (Siemens, Erlangen, Germany) using the quadrature body coil and 12 channel receive only phased array head coil. $|B_l^{(+)}|$ map is obtained using double angle method (flip angle=60° and 120°, TR=1500ms, GRE, 1.4x1.4x5 mm, NEX=3) and $\phi^{(+)}$ is approximated as half of the spin-echo MR phase image when quadrature body coil is used for both transmit and receive. MR signal of each channel of the phased array head coil is acquired using spin-echo pulse sequence when phased array head coil is used for receive. Both simulated and the experimental data are interpolated to triangular mesh nodes and then a matrix equation for u at the nodes is constructed from Eq. (1) using Dirichlet boundary condition (σ and ϵ_r values are specified at the boundary). First and second derivatives of $B_l^{(-)}$ at the triangular mesh nodes are calculated using the method proposed by Fernandez et. al.⁸. A Gaussian filter with standard deviation 0.0014 m is applied to measured $B_l^{(+)}$ and each $B_l^{(-)}$ complex data.

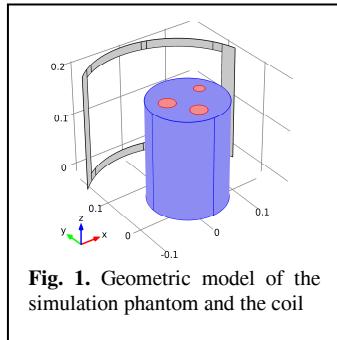


Fig. 1. Geometric model of the simulation phantom and the coil

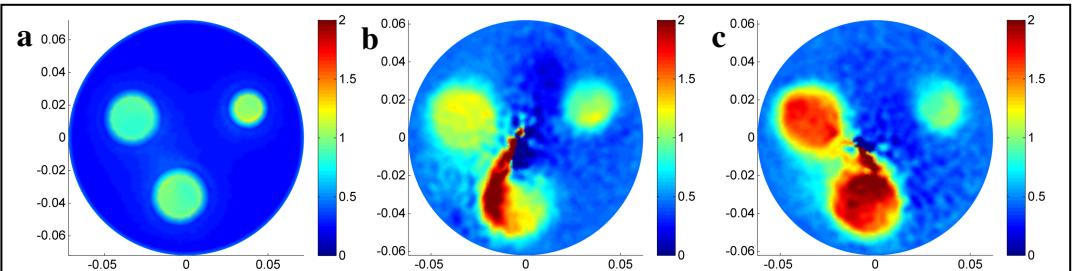


Fig. 2. Reconstructed σ distribution (a) in the simulation using four different $B_l^{(-)}$ data (b-c) in the experiment corresponding to data obtained from two different receive channel separately.

Results: The reconstructed conductivity image obtained in the simulation is shown in Fig. 2a. In this reconstruction, four different $B_l^{(-)}$ complex data are generated by rotating the surface coil (shown in Fig. 1) and therefore we have four different PDE (Eq.1) for the unknown u . The four matrices corresponding to these PDEs are concatenated and u is solved in the least square sense. In the experiment, the conductivity images are reconstructed separately for all 12 channels. In Fig. 2b and c, conductivity distributions reconstructed for two different channels are shown. The conductivity at the boundary of the anomaly objects is well reconstructed. However the conductivity images are distorted in the regions where the convective field is low (LCF region) as also has been observed in a previous study⁵.

Discussion and Conclusion: In this study, a formula to reconstruct the EPs using $B_l^{(-)}$ data is derived and both simulation and experimental results using this formula are given. In the simulations, conductivity distributions using multi receive data are successfully reconstructed. Experimental results show that the method is applicable to a standard quadrature body coil and multi channel receive array coil configuration however further studies needed for eliminating the distorted region. If the LCF regions of any two of receive coils do not coincide, one can use the data of this coils simultaneously to eliminate the distortion as we did in the simulations. Alternatively, asymmetric coils having different LCF regions can be designed or external object (padding) can be used to shift the LCF regions⁶.

References: [1] Haacke E M et al. Phys. Med. Biol. 1991;36(6):471-477 [2] Katscher U et al. IEEE Trans Med Imaging 2009;28(9):1365-1374. [3] Voigt T et al. Magn. Reson. Med. 2011;66(2):456-466. [4] Sodickson et al. ISMRM 21 (2013):4175. [5] Hafalir et al. ISMRM21(2013):4187. [6] Hafalir et al. submitted to IEEE Trans Med Imaging, 2013 [7] Holt DI, Concepts Magn Reson 2000;12:173 [8] Fernandez et al. MIKON-2004;2:585-588

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