Tracking of Sodium Diffusion in Agarose Using MR-EIT

M. J. Hamamura[1], L. T. Muftuler[1], O. Birgul[1], O. Nalcioglu[1]

[1]Tu & Yuen Center for Functional Onco-Imaging, University of California, Irvine, CA, United States

Purpose

It has been reported that the electrical impedance of malignancies is 20-40 times lower than healthy tissues and benign formations [*Malich A. et al, Eur. Radiol. 10: 1555-1561 (2000)*]. Therefore, *in vivo* impedance imaging of suspicious lesions could aid in the diagnosis of malignant tumors. In MR-EIT, electrical currents are injected into an object and the resulting magnetic field perturbations are measured using MRI. These measurements are then used to reconstruct the conductivity distribution within the object. Previous studies on MR-EIT have focused on reconstructing static conductivity distributions. However, the ability to detect changes in conductivity over time could provide additional diagnostic information, such as in monitoring tumor growth. In this study, we assess the ability of MR-EIT to detect these changes.

Methods

Sinusoidal current is injected into an object and the resulting magnetic fields are measured using a modified spin-echo sequence (Figure 1) [*Mikac U. et al, MRI 19: 845-856 (2001)*]. The component of current-generated magnetic field parallel to the main static field (z-component) introduces a phase shift. By synchronizing successive π pulses to half cycles of the current, this phase shift accumulates and is given in the final image as $\varphi(\mathbf{r}) = 4\cdot\gamma\cdot N\cdot b(\mathbf{r}) / \omega$, where γ is the gyromagnetic ratio, N the number of cycles of injected current, $b(\mathbf{r})$ the amplitude of z-component current-generated magnetic field at point $\mathbf{r}$, and ω the angular frequency of the injected current. Hence, measurement of this phase shift allows for calculation of the (z-component) magnetic field distribution.

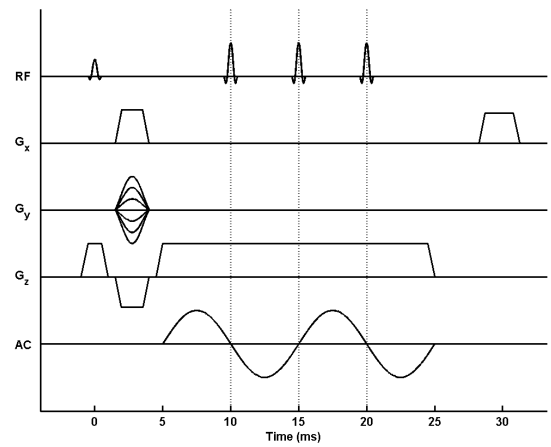

Figure 1. Pulse sequence used in MR-EIT

To reconstruct the conductivity distribution from the magnetic field distribution, a linear approximation $\Delta B(\mathbf{r}) = S(\mathbf{r},\mathbf{r}')\,\Delta\sigma(\mathbf{r}')$ is assumed, where $\Delta B(\mathbf{r})$ is the change in magnetic field at point $\mathbf{r}$ for a given current injection scheme resulting from a change $\Delta\sigma(\mathbf{r}')$ in the conductivity at point $\mathbf{r}'$. The matrix component S_{ij} is the change in magnetic field ∂B_i of element i with respect to a change in the conductivity $\partial\sigma_j$ of element j. An initial conductivity distribution $\boldsymbol{\sigma}_{initial}$ is assumed (e.g. uniform conductivity), the conductivity of a given element j perturbed by $\Delta\sigma_j$, the resulting $\Delta\mathbf{B}$ calculated using the Finite Element Method (FEM), and the matrix components approximated as $S_{ij} = \Delta B_i / \Delta\sigma_j$. The linear approximation can be rewritten as $(\mathbf{B}_{final} - \mathbf{B}_{initial}) = \mathbf{S}\,(\boldsymbol{\sigma}_{final} - \boldsymbol{\sigma}_{initial})$, where $\boldsymbol{\sigma}_{initial}$ is the assumed initial (uniform) conductivity distribution, $\mathbf{B}_{initial}$ the FEM calculated magnetic field distribution given $\boldsymbol{\sigma}_{initial}$, $\mathbf{B}_{final}$ the MRI measured magnetic field distribution, and $\boldsymbol{\sigma}_{final}$ the actual conductivity distribution. The equation is solved for $\boldsymbol{\sigma}_{final}$ using Tikhonov regularization. This $\boldsymbol{\sigma}_{final}$ then substituted back into the linear approximation as the new, updated $\boldsymbol{\sigma}_{initial}$, and the process is iterated until the change in conductivity between successive iterations is below some predefined threshold. Details of this reconstruction method can be found in another abstract submitted concurrently.

The previously outlined method was used to measure the conductivity distribution of an agarose gel phantom. For the phantom, a hollow acrylic disk with an inner diameter of 7cm and thickness of 1cm was filled with 1% (g/100mL) agarose and 1% NaCl. Within this disk, a smaller circular region of 12mm diameter was filled with 1% agarose and 20% NaCl (Figure 2a). Over time, NaCl diffused from the region of higher concentration to the region of lower concentration. Conductivity is assumed proportional to NaCl concentration, hence the conductivity distribution changed as a result of this diffusion. The plane of the disk was placed perpendicular to the z-axis. Four recessed electrodes each 3mm wide were placed equidistant along the circular acrylic wall and used to inject currents into the interior region. Data was collected for two different current injection schemes (in pairs of electrodes directly opposite of each other) and used simultaneously in conductivity reconstruction.

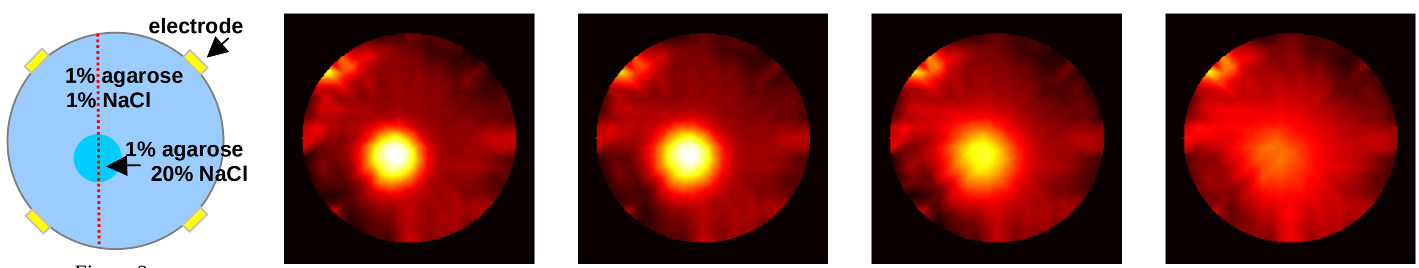

Figure 2a *Figure 2b* *Figure 2c* *Figure 2d* *Figure 2e*

Figure 2. (a) Schematic of the phantom; (b) Conductivity after 20 minutes; (c) 1 hour; (d) 6 hours; (e) 24 hours

Results

2 cycles of 10mA (rms) 100Hz current were injected into the phantom using the previously outlined pulse sequence with the parameters TR=500ms, TE=30ms, and NEX = 4. Scans were taken 20 minutes, 1 hour, 6 hours, and 24 hours after the creation of the phantom. The z-component current-generated magnetic field distributions were calculated from the resulting data and the conductivity distributions computed (Figures 2d-e). The resulting images clearly show a change in the conductivity distribution consistent with the diffusion of NaCl from the higher concentration region to the lower concentration region. Over time, the higher conductivity region broadens, and the border between the initial regions becomes less distinct (Figure 3).

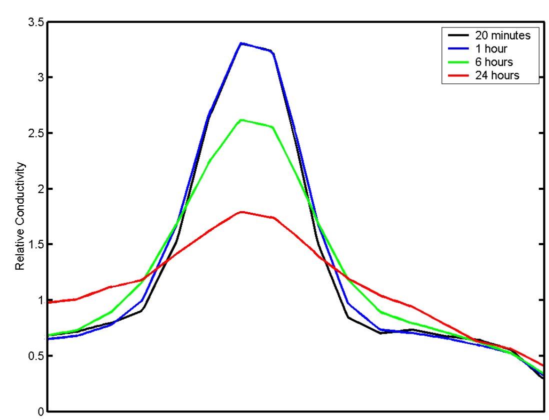

Figure 3. Profile taken across the dotted red line of Figure 2a

Discussion

In this study, we have shown that MR-EIT can be used to monitor changes in conductivity over time. While we assume that conductivity is directly proportional to NaCl concentration for this phantom, future studies will verify this by correlating this method with Sodium MRI. We also plan to monitor malignancies in live animals by performing MR-EIT measurements over the span of several weeks.

Acknowledgement

This research is supported by the Department of Defense DAMD17-02-1-0326.