Dynamic MREIT Using Sub-Milliamp Currents

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Purpose

In Magnetic Resonance Electrical Impedance Tomography (MREIT), electrical currents are injected into an object and the resulting magnetic flux density distribution measured using MRI. These MRI measurements are then used to reconstruct the conductivity distribution within the object. Previous MREIT studies have focused primarily on reconstructing static conductivity distributions. However, the ability to detect changes in conductivity over time could provide additional diagnostic information. We previously reported on the qualitative monitoring of ion diffusion in agarose gel over four time points using MREIT with 10mA injected currents. In this study, we perform a more thorough monitoring using sub-milliamp injected currents more appropriate for human use.

Methods

For the test phantom, a hollow acrylic disk with an inner diameter of 7cm and thickness of 1cm was filled with 2% agarose and 4mM $CuSO_4$. Within this disk, a smaller circular region of 12mm diameter was filled with 2% agarose, 1% NaCl, and 4mM $CuSO_4$ (Figure 2a). Over time, the NaCl diffused from the smaller region into the background, and the conductivity distribution changed. A linear relationship between conductivity and NaCl concentration (of 1% or less) was found after performing a range of conductivity measurements using the 4-electrode technique. The plane of the disk was placed perpendicular to the main static MRI field. Four copper electrodes each 6mm wide were placed equidistantly along the inner acrylic wall and used to inject currents into the interior region.

A finite alternating current pulse waveform with an amplitude of 900uA was injected into the phantom and the resulting magnetic flux density distribution measured using a modified spin-echo pulse sequence (Figure 2) [*Mikac et al, MRI 19: 845-856 (2001)*]. The scan parameters were TR=500ms, TE=60ms, NEX=4, Matrix=64X64, FOV=10cm, and single slice thickness = 5mm. Data was collected for two different current injection schemes (in pairs of electrodes directly opposite of each other) and used simultaneously in conductivity reconstruction. To reconstruct the conductivity distribution using the MRI measurements, the Sensitivity Matrix Method was utilized [*Birgul et al, Phys Med Bio 48: 3485-3504 (2003)*] in which the relationship between conductivity and magnetic flux density is linearized around an initial conductivity (i.e. uniform distribution) and formulated as a matrix equation. This equation is then solved for the true conductivity distribution using Tikhonov regularization. The resulting conductivity can then be substituted back into the linearized equation as the new, updated initial condition, and the process iterated to improve the reconstruction.

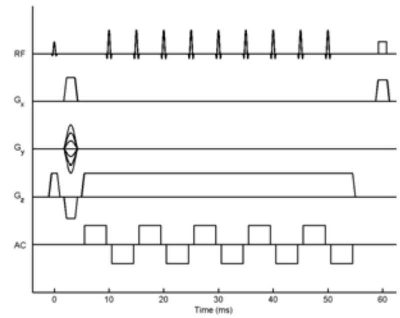

Figure 1. Pulse sequence used in MREIT

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

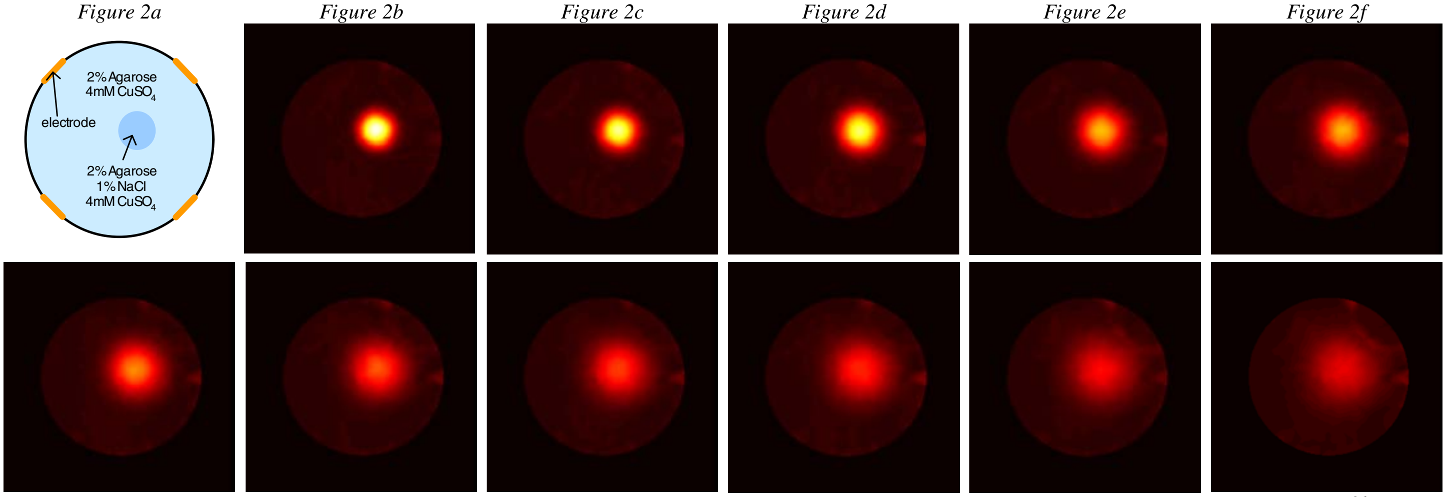

Figure 2g *Figure 2h* *Figure 2i* *Figure 2j* *Figure 2k* *Figure 2l*

Figure 2. (a) Schematic of the phantom; (b) Conductivity after 20 minutes; (c) 1 hour; (d) 2 hours; (e) 3 hours; (f) 4 hours;(g) 5 hours; (h) 6 hours; (i) 7 hours; (j) 8 hours; (k) 10 hours; (l) 12 hours

Results

Data was collected at various time points, and the conductivity distributions reconstructed (Figures 2b-l). 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. For a disk of radius a on an infinite plane surface, the theoretical concentration C at the center of the disk is given as $C=C_0(1-\exp(-a^2/4Dt))$. The peak conductivity values were fitted to this equation, and an experimental diffusion constant of D = 5.8×10^{-6} cm^2 sec^{-1} obtained (Figure 3). This value is smaller than the previously reported measurement of 1.4×10^{-5} cm^2 sec^{-1} [*Schantz et al, Biochem 1: 658-663 (1962)*]. The slower apparent diffusion in this phantom can in part be attributed to its finite shape and confined volume.

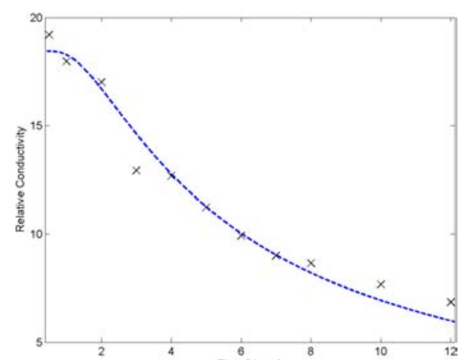

Figure 3. Peak conductivity values

Discussion

The results of this study demonstrate that MREIT can monitor changes in conductivity over time using sub-milliamp injected currents. Validating this ability is a necessary step towards the imaging and monitoring of *in vivo* subjects using MREIT.

Acknowledgement

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