Magnetic Resonance Electrical Impedance Tomography Using Biologically Safe Injected Current Levels

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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. We have recently reported on the measurement of ion diffusion with MREIT using injected current pulses of 900μA [*Hamamura et al, Phys Med Biol 51: 2753-2762 (2006)*]. To our knowledge, this is the lowest level of current successfully used in MREIT to date. However, this level still remains above the required safety limits for application in human studies. The IEC 601 standard limits “patient auxiliary currents” to 100μA at low frequencies. In this study, we assess the efficacy of MREIT using such biologically safe injected current levels.

Methods

Lower injected current levels reduce the SNR of the acquired magnetic flux density maps used in the reconstruction process. To improve the SNR, we utilized a 7T high field system with increased signal averaging to acquire our MRI measurements. For the test phantom, a hollow acrylic disk with an inner diameter of 4.445cm and thickness of 1cm was filled with 2% agarose and 4mM $CuSO_4$. Within this disk, a smaller plastic shell of 6mm diameter was placed slightly off-center to simulate a low conductivity region (Fig. 1). The plane of the disk was placed perpendicular to the main static MRI field. Four copper electrodes each 3mm wide were placed equidistant along the inner acrylic wall and used to inject currents into the interior region.

Fig. 1. Phantom Schematic

A bipolar current pulse was injected into the phantom and the resulting magnetic flux density distribution measured using a modified spin-echo pulse sequence (Fig. 2) [*Scott et al, IEEE TMI 10: 362-374 (1991)*]. The scan parameters were: TR = 500ms, TE = 60ms, matrix = 128X128, FOV = 14cm, and single slice thickness = 1mm. 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 Biol 51: 5035-5049 (2006)*] 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.

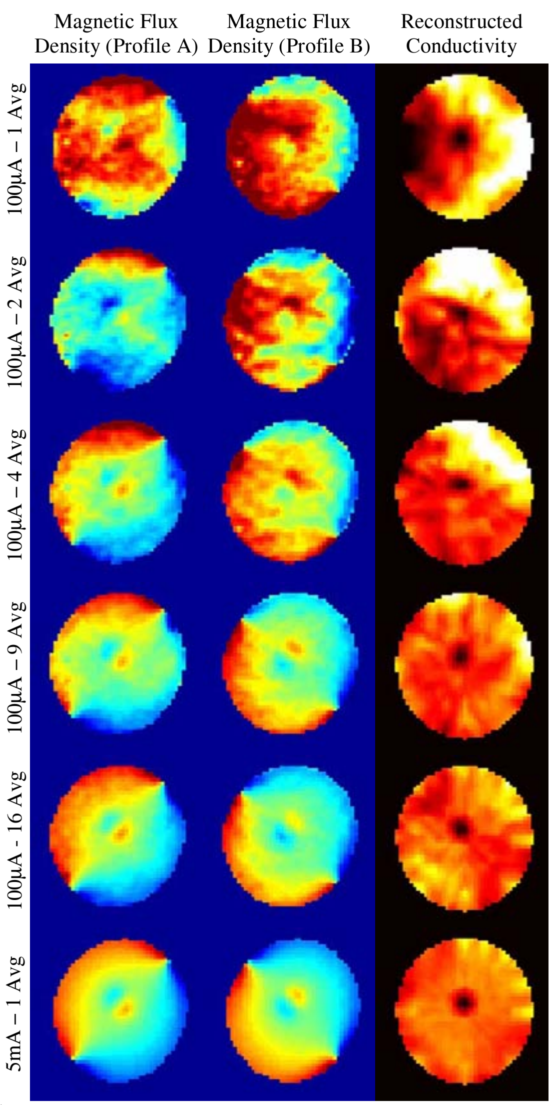

Fig. 3. Magnetic flux density and reconstructed conductivity distributions for various experiments.

Results

Data was collected with various amounts of signal averaging using a current amplitude of 100μA. For comparison, high SNR data was collected by using 5mA of injected current. Relative conductivities were reconstructed for the various data using 5 iterations of the Sensitivity Matrix Method (Fig. 3).

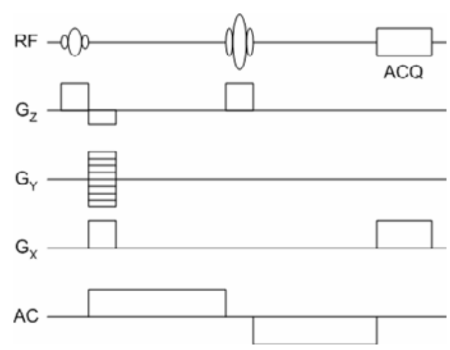

Fig. 2. MREIT Pulse Sequence

Discussion

The results of this study demonstrate that MREIT is capable of reconstructing conductivities using biologically safe injected current levels. Even with a single average, we can observe the lower conductivity perturbation within our test phantom. However, lower SNR data generated considerable variation in the (uniform) background. Improving the SNR through increased signal averaging reduced these artifacts.

When applying MREIT to human studies, the larger object size and 3D current flow will result in a decrease in the measurable magnetic flux density. This study illustrates that increased signal averaging can compensate for this corresponding decrease in SNR. In practice, the presence of correlated noise decreases the efficiency of additional averaging, and places an upper bound on SNR gain. This limitation must be investigated further, as well as other techniques to improve SNR when using low amplitude injected currents.

Acknowledgements

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