Fast Imaging for Magnetic Resonance Electrical Impedance Tomography

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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. Various spin echo based pulse sequences have been proposed to perform this measurement, where a single line of k-space data is collected per excitation. In this study, we investigate the use of a single shot, spin echo, echo planar imaging (SS-SEPI) pulse sequence for acquiring MREIT data.

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 cylindrical region of 13mm diameter was filled with 1% NaCl, 2% agarose, and 4mM $CuSO_4$ to generate a high conductivity region (Figure 1). The plane of the disk was placed perpendicular to the main static MRI field. Two copper electrodes each 6mm wide were placed opposite of each other along the inner acrylic wall and used to inject currents into the interior region.

Fig. 1. Phantom Schematic

A 4mA bipolar current pulse was injected into the phantom and the resulting magnetic flux density distribution measured using a modified SS-SEPI pulse sequence (Figure 2). The component of current-generated magnetic flux density parallel to the main static MRI field (z-component) introduced a phase shift in the MR image given as: $\varphi(\mathbf{r}) = \gamma \cdot (T_A + T_B) \cdot B_Z(\mathbf{r})$. The scan parameters were: T_A = 35ms, T_B = 10ms, TR = 3ms, TE = 60ms, matrix = 64X64, FOV = 20cm, and single slice thickness = 5mm. Data was collected twice, each with opposite polarities in the applied current waveform. The resulting phase maps were subtracted then divided by two, so as to cancel out any additional phase contributions, such as those arising from small imperfections in the hardware timing.

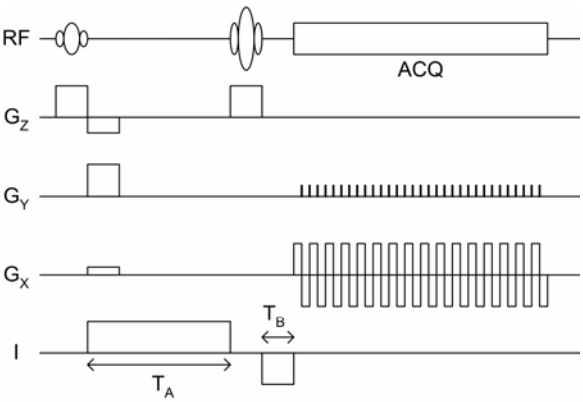

Fig. 2. SS-SEPI pulse sequence for MREIT

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 z-component 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.

Results

Data was collected using a 4T MRI system. For comparison, data was also acquired using no injected current, and also using the original SE-based measurement sequence [*Scott et al, IEEE TMI 10: 362-374 (1991)*]. Relative conductivities were reconstructed for the various data using 5 iterations of the Sensitivity Matrix Method (Figure 3). As part of the reconstruction process, a Finite Element Method mesh was aligned to the MR image, and for the (geometrically distorted) SS-SEPI data, the resulting conductivity map linearly transformed back into a circular geometry.

Discussion

Comparison of the 0mA and 4mA cases shows that the SS-SEPI pulse sequence was able to detect the magnetic flux density generated by the injected current. Comparison with the SE results shows that the SS-SEPI pulse sequence was also able to map out the general variation in the magnetic flux density due to the high conductivity perturbation. However, the SS-SEPI images suffer from geometric distortions resulting from the low sampling bandwidth in the phase encode direction inherent in EPI-based pulse sequences. As a result, the reconstructed conductivity distribution also suffers from some geometric distortion. Never the less, the high conductivity perturbation could still be reconstructed from the SS-SEPI data. We could further improve reconstruction by applying some sort of geometric correction to the MRI data.

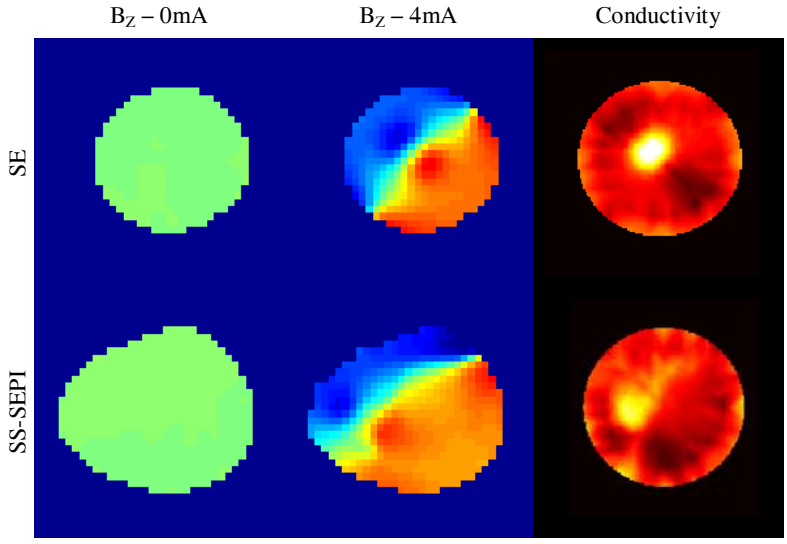

Fig. 3. Magnetic flux density and reconstructed conductivity distributions

An advantage of the SS-SEPI pulse sequence is the significant reduction in data acquisition time. This could allow for increased signal averaging in an allotted study time, which may be required for improving the SNR when using low amplitude injected currents. Single shot pulse sequences are also less susceptible to motion artifacts, which may be of significance when applying MREIT to *in vivo* studies.

Acknowledgements

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