Multiple Current Injection Schemes In 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. These MRI measurements are then used to reconstruct the conductivity distribution within the object. In order to determine the conductivity distribution uniquely, data from at least two different current distributions satisfying $|\mathbf{J}_1(x,y)\times\mathbf{J}_2(x,y)|\neq 0$ must be acquired [*Kwon O. et al, IEEE Trans on BME 49: 160-167 (2002)*]. Typically, two electrodes are used to provide one current distribution, and two additional electrodes are used to provide a second current distribution, for a total of four electrodes and two current injection schemes. However, with four electrodes, one can apply up to six different current injection schemes using different pairs of electrodes (Figure 1). In this study, we assess the effects of utilizing these additional current injection schemes.

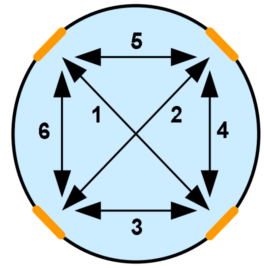

Figure 1. Multiple Current Injection Schemes

Method

For the test phantom, a hollow acrylic disk with an inner diameter of 7cm and thickness of 1cm was filled with 2% agarose, 0.1% NaCl, and 4mM $CuSO_4$. Within this disk, a three smaller circular regions each 1cm in diameter were filled with 2% agarose, 1% NaCl, and 4mM $CuSO_4$ (Figure 3). The conductivities of the different regions were measured using the 4-electrode method and found to yield a contrast ratio of 1 to 7.4. The plane of the disk was placed perpendicular to the main static MRI field. Four copper electrodes each 6mm wide were placed equidistant 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. 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. A separate equation is generated for each current injection scheme, and various combinations of these equations can be combined to solve for the conductivity distribution. The solution is obtained using Tikhonov regularization. The resulting conductivity can then be substituted back into the linearized equation(s) as the new, updated initial condition, and the process iterated to improve the reconstruction.

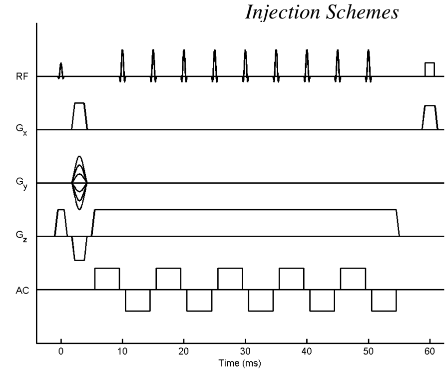

Figure 2. Pulse sequence used in MREIT

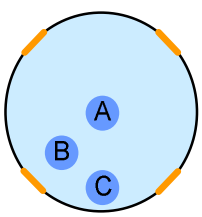

Figure 2. Schematic of phantom

Schemes	1,2	1,2,3	1-6
Region A	6.3398	5.6022	5.2355
Region B	6.3299	5.7407	5.3522
Region C	3.6669	3.6327	3.6439

Table 1. Peak conductivities

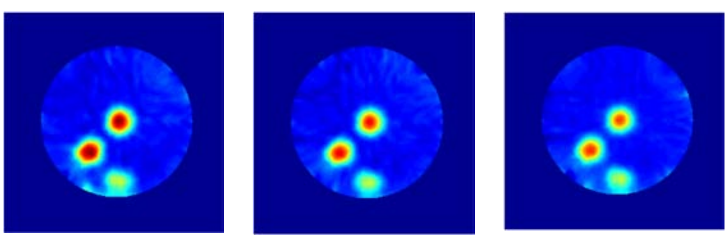
Figure 4a *Figure 4b* *Figure 4c*
Fig 4. Reconstructed conductivity using injection schemes: (a) 1,2; (b) 1,2,3; (c) 1-6

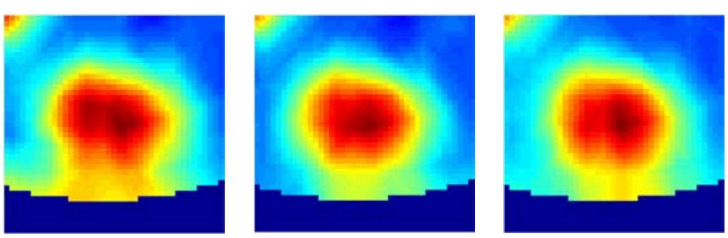
Figure 5a *Figure 5b* *Figure 5c*
Figure 5. Conductivity of Region C for injection schemes: (a) 1,2; (b) 1,2,3; (c) 1-6

Results

Data was collected for each of the 6 current injection schemes. Conductivity distributions were reconstructed for different combinations of data sets using 5 iterations of the Sensitivity Matrix Method (Figures 4a-c). For each reconstructed image, the peak conductivity in each of the three inner regions A, B, and C was found (relative to the background conductivity of 1), and the results compiled in Table 1. A closer view of region C was also extracted (Figures 5a-c).

Discussion

The results indicate that reconstructing periphery regions away from the injecting electrodes presents difficulties, regardless of the current injection schemes used. From inspection of Figure 5, including data from the periphery injection schemes (3-6 in Figure 1) improves the overall shape of object C. In particular, adding scheme 3 provides the largest current density to the region of interest and appears to best improve the spatial distribution. However, overall contrast is best when using only the standard orthogonal injection schemes (1 and 2). Using additional injection schemes further reduces contrast throughout the object.

Selecting which current injection schemes to use requires balancing overall contrast with improved spatial resolution in the periphery regions, and will thus depend on the object to be imaged and the desired information. The increased scan time required to collect data from addition current injection schemes must also be considered.

Acknowledgement

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