Improved MREIT Reconstruction Using Sodium MRI

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Purpose

Several studies have reported that the electrical impedance of malignancies is lower than healthy tissues and benign formations [Malich *et al*, Eur Radiol 10:1555-1561 (2000)]. Since tissue conductivity is largely ionic, this higher conductivity may be the result of an increase in extracellular sodium. 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 this study, we investigated the incorporation of sodium MRI data to improve MREIT conductivity reconstruction.

Methods

For the test phantom, a hollow acrylic disk with an inner diameter of 7cm and thickness of 2cm was filled with 5% NaCl, 2% agarose, and 4mM $CuSO_4$. Within this disk, a smaller cylindrical shell of 25mm outer diameter and 9mm inner diameter was filled with no NaCl, 2% agarose, and 4mA $CuSO_4$ to generate a low conductivity region (Fig. 1). The innermost disk formed a third region with the same composition as the background. The plane of the phantom was placed perpendicular to the main static MRI field. Three copper electrodes each 3mm wide were placed equidistant along the inner acrylic wall and used to inject currents into the interior region.

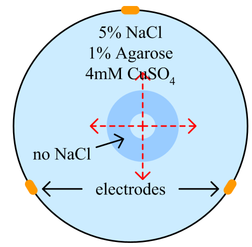

Fig. 1. *Phantom Schematic*

Data was collected using a 4T MRI system. A 1mA bipolar current pulse was injected into the phantom and the resulting magnetic flux density distribution measured using a modified SE pulse sequence (Fig. 2) [Scott *et al*, IEEE TMI 10:362-374 (1991)]. Scan parameters were: TR = 500ms, TE = 50ms, T_C = 45ms. FOV = 10cm, matrix = 128x128, slice thickness = 5cm, NEX = 2. Data were collected twice with different pairs of injecting electrodes and used simultaneously in the conductivity reconstruction. Sodium MRI data were acquired using a 3D radial projection pulse sequence (Fig. 3) [Nielles-Vallespin *et al*, MRM 57:74-81 (2007)]. Scan parameters were: TR = 100ms, TE = 250µs, FOV = 20cm, # radial lines = 5000, resampled matrix = 64x64x64.

To reconstruct the conductivity distribution using the MRI measurements, the sensitivity matrix method (SMM) was utilized in which the relationship between conductivity and *z*-component magnetic flux density is linearized around an initial conductivity and formulated as a matrix equation [Birgul *et al*, Phys Med Biol 51:5035-5049 (2006)]. In our previous studies, a uniform conductivity distribution was used for the initial condition. In this study, we investigated using the sodium MR image to generate an *a priori* conductivity map, where the (relative) conductivity values were proportional to the measured sodium concentrations.

The SMM linear equation is solved for the actual conductivity distribution using Tikhonov regularization. The solution is then substituted back into the linear equation as the new, updated initial condition, and the process iterated to improve the reconstruction. In our previous studies, the regularization parameter was selected such that magnetic flux density generated by the reconstructed conductivity distribution was closest to the MRI-measured magnetic flux density. In this study, we investigated using the regularization parameter that maximized the mutual information between the reconstructed conductivity distribution and the sodium MR image.

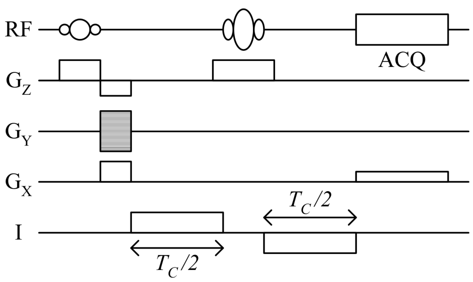

Fig. 2. *MREIT pulse sequence*

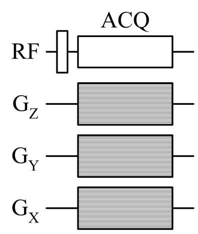

Fig. 3. *Sodium pulse sequence*

Results

Proton MR, sodium MR, and MREIT data were collected (Fig. 4). Relative conductivities were reconstructed using five iterations of the SMM for three variations in the reconstruction algorithm: no incorporation of sodium MRI data (REG); use of the sodium MR image as an *a priori* to generate an initial condition (APRI); and maximization of the mutual information between the sodium MR image and the reconstructed conductivity (MUT). The average profile of the inner shell across the red dotted lines in Fig. 1 was calculated for each of the three methods (Fig. 5).

Discussion

The results of this study demonstrate that sodium MRI data can be incorporated into the MREIT reconstruction algorithm to improve the accuracy of the resulting conductivity maps. APRI improved reconstruction of the inner high conductivity region, while MUT improved reconstruction of the low conductivity shell. This improved reconstruction was accompanied by a slight increase in artifacts in the background region. This may be the result of utilizing a somewhat noisy sodium MR image. We hypothesize that higher SNR sodium MRI data will reduce these artifacts. The algorithms were also unable to reconstruct the full conductivity range across the phantom. The relatively low injected current level (1 mA), along with a reduction of current density in the central region due to the low conductivity shell, results in a decrease in the SNR of the magnetic flux density measurements, which degrades the conductivity reconstruction. This study demonstrates that sodium MRI data can be used to reduce such degradation.

Acknowledgement

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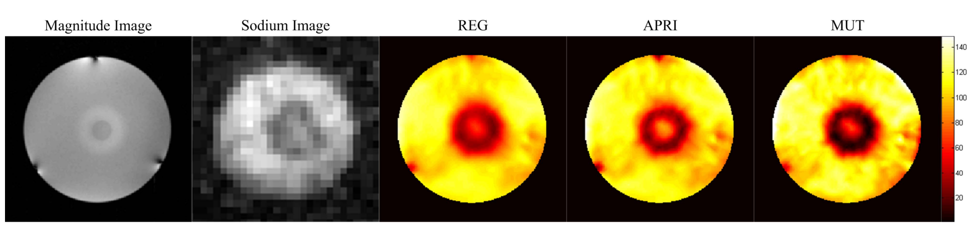

Fig 4. *Magnitude image, sodium image, and reconstructed conductivity distributions*

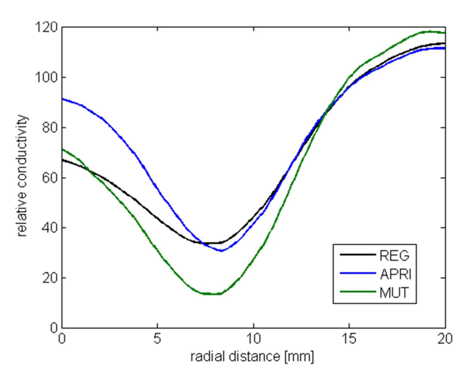

Fig. 5. *Radial profile of conductivity*