

# Incorporation of ADC Information Into SMM-based MREIT for Small Animal Conductivity Imaging

M. J. Hamamura<sup>1</sup>, O. Nalcioglu<sup>1</sup>, and L. T. Muftuler<sup>1</sup>

<sup>1</sup>Tu & Yuen Center for Functional Onco-Imaging, University of California, Irvine, CA, United States

## Purpose

Several *ex vivo* studies have reported that the electrical impedance of malignancies is lower than healthy tissues and benign formations [Malich *et al*, Eur Radiol 10:1555-61 (2000)]. Therefore, *in vivo* conductivity imaging may have potential applications in tumor diagnosis. Magnetic resonance electrical impedance tomography (MREIT) is an emerging, non-invasive conductivity imaging modality, in which electrical currents are injected into an object and the resulting magnetic flux density distribution is measured using MRI; these MRI measurements are then used to reconstruct the conductivity distribution within the object.

Only a very limited number of *in vivo* MREIT studies have been reported. Restrictions on the (safe) injected current level and total scan time limit the signal-to-noise ratio (SNR) of the MREIT data. To improve the conductivity reconstruction using this lower SNR data, we incorporated additional *a priori* information. Tuch *et al* have reported a linear relationship between tissue conductivity and the diffusion tensor [PNAS 98:11697-701 (2002)]. Thus, we generated the apparent diffusion coefficient (ADC) map and incorporated this information into the MREIT reconstruction algorithm.

## Methods

A female Fischer-344 rat bearing the R3230 malignant tumor was utilized in this study. Data was collected using a 4 T MRI system. Anatomical and diffusion-weighted images were acquired using a standard spin-echo (SE) pulse sequence with parameters: TR = 1 s, TE = 50 ms, FOV = 10 cm, matrix = 128x128, slice thickness = 5 mm, NEX = 2, b-value ≈ 0, 500. Three copper electrodes each 5mm long and 2 mm wide were then placed on the animal's surface (at the red arrows of Fig. 2b) and used to inject currents into the body. A custom holder was utilized to fix the positions of the animal, electrodes, and lead wires. A 1 mA bipolar current pulse was injected into the animal and the resulting z-component magnetic flux density distribution  $B_z$  was measured using a modified SE pulse sequence [Scott *et al*, IEEE TMI 10:362-374 (1991)] as diagrammed in Fig. 1. Scan parameters were: TR = 500 ms, TE = 50 ms,  $T_A + T_B = 46$  ms, FOV = 10 cm, matrix = 128 x 128, slice thickness = 5 cm, NEX = 4. Two  $B_z$  maps were calculated using electrode pairs 1&2 and 1&3 respectively for current injection, and used simultaneously in the conductivity reconstruction.

To reconstruct the conductivity distribution using the MRI measurements, the sensitivity matrix method (SMM) with Tikhonov regularization was utilized, where the relationship between conductivity and magnetic flux density is linearized around an initial conductivity (i.e. uniform distribution) and formulated as a matrix equation [Birgul *et al*, Phys Med Biol 51:5035-5049 (2006)]. The solution is then substituted back into the linear equation as the new, updated initial condition, and the process iterated to improve the results. In our previous animal studies, the regularization parameter was selected such that the magnetic flux density generated by the reconstructed conductivity distribution was closest to the MRI-measured magnetic flux density. However, the solution did not always converge using this criterion, as was the case with the data of this study. Instead, we investigated using the regularization parameter that maximized the mutual information between the reconstructed conductivity distribution and the relative ADC map.

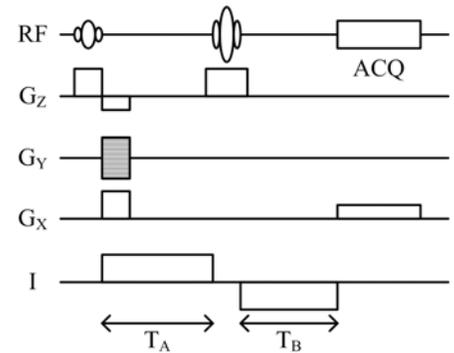


Fig 1. MREIT pulse sequence

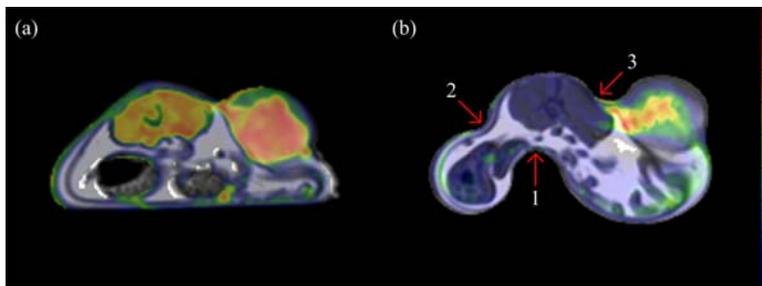


Fig. 2. (a) Relative ADC and (b) relative conductivity maps overlaid onto the anatomical images. The colorbar scale is shown on the right.

fibers). However, the injected current was largely within the imaging plane and perpendicular to the muscle fibers, thus explaining the lower apparent conductivity. Never the less, use of this ADC map for regularization in the SMM allowed us to generate a sensible conductivity reconstruction.

Previous studies found that the presence of copper electrodes adversely affects diffusion-weighted imaging. Hence for this study, diffusion data was acquired without the electrodes. The animal was then placed within the electrode/lead wire holder for MREIT imaging. As a result, image warping and registration were needed to utilize both data sets together in the conductivity reconstruction. For future studies, we will investigate the use of alternate materials to allow for artifact-free diffusion imaging with electrodes. This would allow us to acquire all data sets without altering the geometry of the animal.

Limited SNR data, along with motion and chemical shift artifacts, present a significant challenge to generating accurate *in vivo* conductivity maps in MREIT. This study demonstrates that incorporation of additional *a priori* information such as the ADC map can improve the reconstruction in the face of these challenges.

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## Results

The relative ADC map was computed using the anatomical and diffusion-weighted images, and shown in Fig. 2a. After appropriate warping and registration, this ADC map was then utilized in five iterations of the SMM to reconstruct the conductivity distribution (Fig. 2b).

## Discussion

Comparison of Figs. 2a and 2b reveal that while diffusion and conductivity may be correlated, they are not identical. The ADC map shows higher values in both the tumor and muscle regions, while high conductivity is limited to part of the tumor. Diffusion gradients were applied along all 3 axes, thus the ADC map accounted for diffusion along all dimension (i.e. along the muscle