Reconstruction of Irregular Conductivity Distributions using MREIT at Low Current Levels

O. Birgul[1], L. T. Muftuler[1], M. J. Hamamura[1], O. Nalcioglu[1]

[1]Tu & Yuen Center for Functional Onco Imaging, University of California, Irvine, CA, United States

Purpose

It is possible to detect locations of lesions in breast cancer using techniques such as x-ray mammography or MRI accurately, however, the specificity of current techniques is low [1]. Since the conductivity values of malignant, benign, and normal tissues are significantly different, this information can be used in classification to improve specificity. Magnetic resonance-electrical impedance tomography (MREIT) is an imaging modality that reconstructs conductivity images from magnetic field measurements generated due to a current distribution in a volume conductor. In MREIT low amplitude sinusoidal current is injected into an object and the resulting magnetic field accumulated additional phase in MR images. A modified fast spin-echo sequence is used to measure this magnetic field. These measurements are used to solve the inverse problem of finding the conductivity distribution inside the object using an iterated sensitivity reconstruction algorithm. In most cases, the conductivity distribution is expected to vary within the tumor. There are several phantom studies in literature that assess the performance of MREIT using simple cases but none investigates whether it is capable of detecting complex and nested conductivity distributions, which models the real life cases more accurately. In this study, we used a new criterion for selection of optimum regularization parameter in image reconstruction and showed that it is possible to resolve a 6mm inhomogeneity within an irregular region using lmA peak current.

Methods

Reconstruction of conductivity involves two basic steps. The first step is the measurement of magnetic flux density using magnetic resonance imaging. This step involves MRI data acquisition using a modified spin echo pulse sequence [2] and generation of magnetic flux density images from MRI phase images using scaling. The component of the magnetic flux density in the direction of the main static field of MRI is sufficient in image reconstruction. In the second step, these images are used as input data in the inverse problem of finding conductivity from magnetic field information. Sensitivity based reconstruction algorithm is implemented for the solution of the inverse problem. Uniform conductivity distribution is assumed and sensitivity matrix is calculated analytically [3]. Resulting matrix equation is given as $\Delta\mathbf{b} = \mathbf{S}\Delta\boldsymbol{\sigma}$ where $\Delta\mathbf{b}$ is the difference between measured magnetic flux density and the magnetic flux density corresponding to initial distribution, $\Delta\boldsymbol{\sigma}$ is the change with respect to initial and $\mathbf{S}$ is the sensitivity matrix that gives the relation between changes in magnetic field and conductivity. Including Tikhonov regularization parameter, λ, the matrix equation becomes $(\mathbf{S}^T\mathbf{S} + \lambda\mathbf{I})\,\Delta\boldsymbol{\sigma} = \mathbf{S}^T\Delta\mathbf{b}$ where $\mathbf{I}$ is the identity matrix. The matrix equation is solved for different values of λ using conjugate gradient method and the optimum regularization value is selected as the one minimizing the difference

$$\min_{\lambda} \sum_{i=1}^{m} \left\| B_{meas,i} - B_{calc,i}(\lambda) \right\|$$

where m is the total number of measurement points, B_{meas} is the measured magnetic flux density, and B_{calc} is the flux density calculated using reconstructed conductivity. Calculated conductivity distribution is assigned as the initial value and the steps starting with sensitivity matrix calculation are repeated until the change in conductivity two consecutive iterations are below a defined threshold.

Results

A three region conductivity phantom is generated using agarose and different concentrations of NaCl (Fig 1a). For the background, 1% (g/100mL) agarose and 1% NaCl is used. Agarose amount is kept constant in all regions but NaCl is increased to 2% and 4% for regions II and III respectively. Corresponding conductivity values are measured using a 4 electrode conductivity cell and the true values are found to be 1.54, 2.94, and 5.92mS/cm. Four electrodes are placed around the object giving 6 different current injection profiles. First, high-resolution anatomical images are acquired to determine the exact locations of the electrodes to be used in the image reconstruction (Fig 1b). Since the water content is same in all regions, the irregular region and the 6mm inclusion cannot be seen in the MR image. Then 4 cycles of 1mA (peak) 100Hz current were injected with TR = 1000ms, TE = 50ms, and NEX = 4 and field is measured for 6 cases (Fig 1c). Measurements around the outer ring are masked out to eliminate spurious boundary effects in images reconstruction. Reconstructed conductivity image is given in Fig 1d. where the 6mm region inside the irregular image is resolved. Peak reconstructed values for each region are 1.23, 2.55, and 4.93mS/cm for each region.

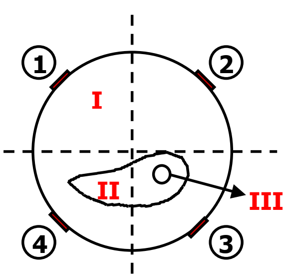

Figure 1a

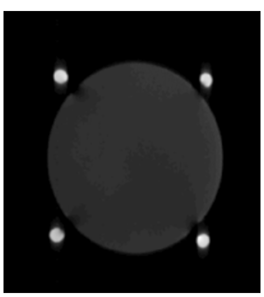

Figure 1b

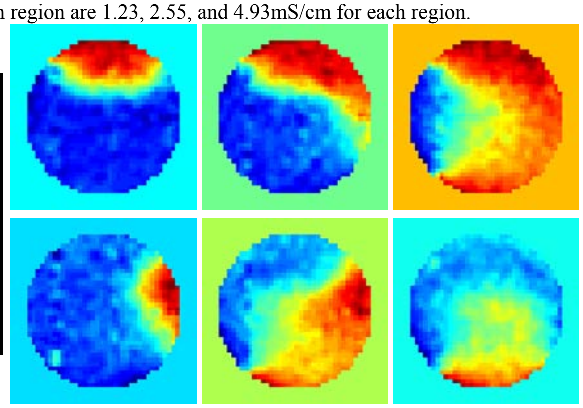

Figure 1c

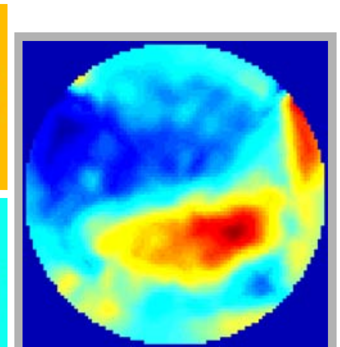

Figure 1d

Figure 1 (a) Schematic of the multi-compartment conductivity phantom (b) MR magnitude images (c) Scaled and masked MR phase images for 6 different current injection case (d) reconstructed conductivity image (red indicating higher conductivity and blue indicating lower conductivity

Discussion

In this study, we have shown that it is possible to reconstruct complex conductivity distributions within an object using MREIT technique and iterated sensitivity reconstruction algorithm. The irregular object and 6mm inclusion, which cannot be seen in the anatomical MR images, are clearly resolved in the conductivity image with 16.7% peak error at current levels which are acceptable for human imaging applications.

References

[1] Malich A, *et. al.*, *Eur. Radiol*, 10: 1555-1561 (2000), **[2]** Muftuler L T, *et. al.,TCRT* December 2004 **[3]** Birgul O, *et. al.* PMB, 48: 3485-2504 (2003)

Acknowledgments

This research is supported in part by Department of Defense Award W81XWH-04-1-0446 and NIH/NCI Award R01 CA114210.