A Comparison of MRI Based Electrical Impedance Imaging and Contrast Enhanced MRI of Tumors

L. Muftuler[1], M. Hamamura[1], O. Birgul[1], O. Nalcioglu[1]
[1]Functional Onco-Imaging Center, University of California, Irvine, CA, United States

Purpose

Malich et al has reported that the electrical impedance of malignancies could be 20-40 times lower than healthy tissues and benign formations [*Malich A. et al, Eur. Radiol. 10: 1555-1561 (2000)*]. Therefore, in-vivo impedance imaging of suspicious lesions could aid in improving the sensitivity and specificity of detecting malignant tumors. MRI based impedance imaging is a novel method, in which weak electrical currents are injected into the tissue and the resulting perturbations in magnetic field were measured using MRI. On the other hand, contrast enhanced imaging is a well-established method to detect malignant tissues. Since vascular growth is greatly enhanced in tumor structures, contrast agent uptake of tumor sites are increased with respect to normal tissues. In addition to that, interstitial compartment in tumors are larger compared to normal structures, so wash-out of contrast agent is also slower in tumors. Therefore, if two images are collected, one pre-contrast and the other post-contrast, the difference image will yield enhanced pixel intensity in the areas of tumor growth. In this study, our goal is to verify the potential of MR-EIT to detect tumors.

Methods

Sinusoidal current is injected into an object and the resulting magnetic fields are measured using a modified spin-echo sequence (Fig. 1) [*Mikac U. et al, MRI 19: 845 856 (2001)*]. The z-component of magnetic field (parallel to the main static field) generated by injected currents introduces a phase shift. By synchronizing successive π pulses to half cycles of the current, this phase shift accumulates and is given in the final image as $\varphi(\mathbf{r}) = 4\cdot\gamma\cdot N\cdot b(\mathbf{r}) / \omega$, where γ is the gyromagnetic ratio, N the number of cycles of injected current, $b(\mathbf{r})$ the amplitude of z-component current-generated magnetic field at point $\mathbf{r}$, and ω the angular frequency of the injected current. Hence, measurement of this phase shift allows for calculation of the (z-component) magnetic field distribution. To reconstruct conductivity image, a linear approximation $\Delta B(\mathbf{r}) = S(\mathbf{r},\mathbf{r}')\,\Delta\sigma(\mathbf{r}')$ is assumed, where $\Delta B(\mathbf{r})$ is the change in magnetic field at point $\mathbf{r}$ for a given current injection scheme resulting from a change $\Delta\sigma(\mathbf{r}')$ in the conductivity at point $\mathbf{r}'$. S is calculated using Finite Element Method (FEM). The matrix component S_{ij} is the change in magnetic field ∂B_i of element i with respect to a change in the conductivity $\partial\sigma_j$ of element j. An initial conductivity distribution $\boldsymbol{\sigma}_0$ is assumed (e.g. uniform conductivity), the conductivity of a given element j is perturbed by $\Delta\sigma_j$ and the resulting $\Delta\mathbf{B}$ is calculated. $\mathbf{S}$ is inverted to obtain $\Delta\boldsymbol{\sigma} = \boldsymbol{\sigma}_{final} - \boldsymbol{\sigma}_{initial} = \mathbf{S}^{-1}\,\Delta\mathbf{B} = \mathbf{S}^{-1}\,(\mathbf{B}_{final} - \mathbf{B}_{initial})$, where $\boldsymbol{\sigma}_{initial}$ is the assumed initial (uniform) conductivity distribution, $\mathbf{B}_{initial}$ the magnetic field distribution given $\boldsymbol{\sigma}_{initial}$, $\boldsymbol{\sigma}_{final}$ the actual conductivity distribution, and $\mathbf{B}_{final}$ the MRI measured magnetic field distribution. Hence, the conductivity distribution of an object is $\boldsymbol{\sigma}_{final} = \mathbf{S}^{-1}\,(\mathbf{B}_{final} - \mathbf{B}_{initial}) + \boldsymbol{\sigma}_{initial}$.

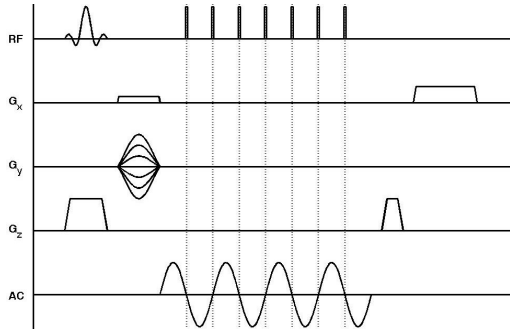

Fig. 1. Pulse sequence used in MR-EIT

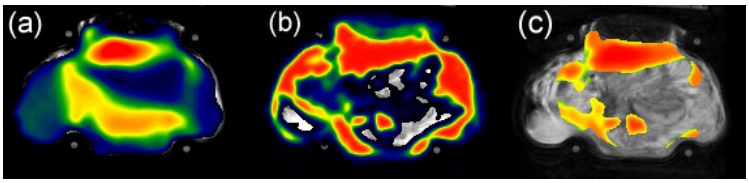

Fig.2. (a) Conductivity distribution. Red: high conductivity, blue: low conductivity; (b) difference of pre and post Gd-DTPA images. Red: regions enhanced by Gd-DTPA; (c) Areas that have both high conductivity and also enhanced by contrast agent.

Results

An anatomical image was collected using FSE sequence prior to MR-EIT images. The data matrix was 256X256, FOV = 10cm, slice thickness = 6mm TR = 4s, TE = 20ms/100ms NEX = 4. MR-EIT images were collected using the previously outlined pulse sequence with TR=2s, TE=32ms, and NEX=8, 64X64 data matrix, FOV = 10cm, slice thickness = 6mm, with an AC current of 1mA peak, 200Hz, 4 cycles. Contrast enhanced images were collected using GE sequence with 64X64 data matrix, FOV = 10cm, 6mm slice thickness, TR = 150ms TE = 5ms and 45^0 flip angle. One pre-contrast image was acquired before Gd-DTPA injection and a post-contrast image was collected 3 minutes after injection. Relative conductivity distribution was computed as described above and overlaid on anatomical image (Fig. 2a). The resulting images clearly show the higher conductivity regions. Similarly, the contrast enhancement by Gd-DTPA is illustrated in Fig. 2b. Fig 2.c. shows regions that have high conductivity and also enhanced by Gd-DTPA. This image is generated by masking Gd-DTPA images with regions that have conductivity values in the upper one-third of the full range.

Discussion

In this preliminary study, we have shown that MRI based impedance imaging can be used to detect malignant tumors. It can be seen from these results that there is high correlation between conductivity images and contrast enhanced images. Although they do not completely overlap, this is expected because the two methods emphasize different properties of tumors. For example, edema will most likely show high conductivity but will not show signal enhancement with Gd-DTPA. To exclude edema regions from conductivity images, one can use T2 weighted sequences that highlights edema. In this preliminary experiment, we imaged an animal with a large tumor size, which was currently available. In large tumors, various compartments like edema, necrosis and viable tumor cells exist and their conductivity and contrast agent enhancement will be different. Currently we are working on a longitudinal study to observe changes in conductivity as well as Gd-DTPA based contrast enhancement in tumor structures as the tumor grows. Gd enhanced images will be used to verify our results in vivo. At the end of the study, tumors will be excised and undergo histologic analysis. Contrast enhanced and T2 weighted images together with MR-EIT maps will allow us to assess how conductivity correlates with different compartments of tumors. Electrode position and number could be another factor that may confound detection of some low conductivity structures close to surface. We will also investigate effects of electrode placement in our future experiments.

Acknowledgements:

This research is supported by Department of Defense DAMD17-02-1-0326.