In Vivo MRI Based Electrical Impedance Tomography of Malignant Tumors

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Purpose

Several studies have shown that the electrical impedance of malignant tissues is significantly different from those of normal and benign tissues [1,2]. Therefore, in-vivo impedance imaging of suspicious lesions has the potential to improve the sensitivity and specificity of detecting malignant tumors. MR-Electrical Impedance Tomography (MREIT) has been recently introduced, in which weak electrical currents are injected into the tissue and the resulting perturbations in magnetic field were measured using phase information in MR images. We have reported our preliminary studies with phantoms as well as two *in vivo* experiments [3]. Here, we present the results of MREIT done on eleven animals. Parameters like variance and mean in the tumor versus the rest of the body were investigated. The goal is to verify potential of MR-EIT to aid in the diagnosis of tumors.

Methods

Weak electrical currents that are injected into an object generate magnetic fields, the z-component of which induces additional phase information in MR images. If a modified spin-echo sequence was used with several π pulses applied during the zero-crossings of the alternating current, the phase shift accumulates across these π pulses and is given in the final image as $\varphi(\mathbf{r}) = 4\cdot\gamma\cdot N\cdot b_z(\mathbf{r}) / \omega$, (γ: gyromagnetic ratio; N: the number of cycles of injected current; $b_z(\mathbf{r})$: the amplitude of current-generated magnetic field at point **r;** ω: angular frequency of the injected current). Here $b_z(\mathbf{r})$ is calculated from the phase $\varphi(\mathbf{r})$ measurements. We have implemented an iterative reconstruction with Tikhonov regularization to reconstruct the conductivity images from $b_z(\mathbf{r})$: $\mathbf{S^T\Delta b_z(r) = (S^TS+\lambda I)\ \Delta\sigma(r')}$. Here the *sensitivity matrix* S is calculated using Finite Element Method; $\Delta b_z(\mathbf{r})$ is the change in magnetic field at point **r** for a given current injection scheme resulting from a change $\Delta\sigma(\mathbf{r}')$ in the conductivity at point **r'**, λ is the *regularization parameter* and **I** is the identity matrix. The details were given in [4].

Data were collected in a whole body 4T MRI system with a MRRS console. Eleven rats were imaged, ten of which were bearing malignant tumors that were either R3230AC tumor grafts or induced by the carcinogen ENU. Animals were anesthetized prior to imaging and all procedures were approved by the IACUC. Two data sets were discarded due to severe motion artifacts. Structural images were collected using T2 weighted SE sequence prior to MREIT images. The data matrix was 128X128, FOV = 10cm, slice thickness = 4mm, with 2mm gap. TR = 3s, TE = 50ms and NEX = 2 were used. MREIT images were collected using the outlined pulse sequence with TR=1000ms, TE=30ms, and NEX=2, 64X64 data matrix, FOV = 10cm, slice thickness = 4mm with 2mm gap. Two cycles of 100Hz current with 1mA rms was applied sequentially through different pairs of four electrodes, generating six different current profiles. Data were collected with both ± polarities of the currents to eliminate phase accumulation from other sources.

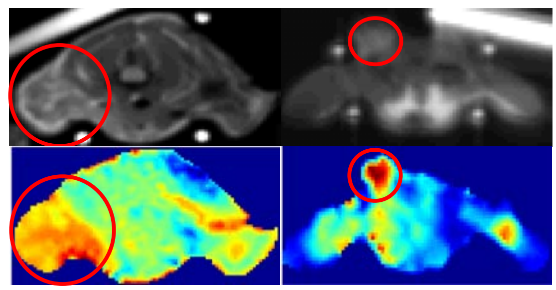

Fig.1. Results from two animals are illustrated. T2 weighted scans are displayed above and corresponding impedance (MREIT) images are depicted in color right below. Tumor areas are marked with red circles.

Results and Discussion

Fig.1 shows T2 weighted MRI and MREIT images of two rats. Tumor areas show increased conductivity depicted with yellow-red colors. On the MREIT images of the animals, separate ROIs (region of interest) were drawn over the tumor region and the rest of the body and the mean conductivity values in these ROIs were calculated. Since MREIT yields relative conductivity values, the conductivity ratio $\sigma_{tumor}/\sigma_{body}$ was calculated for each animal and the graph is shown in Fig.2. It was found that the average of these conductivity ratios was 2.17. ROIs were drawn manually based on the tumor seen in MRI T2 images. We have also calculated the ratio of standard deviation to mean conductivity in each tumor region, which may be an indication of *conductivity heterogeneity* inside the tumor volume, rather than SNR (Fig.3). As seen from these figures, consistent results were obtained from these eight animals. Average conductivity increased by roughly 2.2 times in the tumor compared to the rest of the body. The conductivity varied typically between 10% and 20% within the tumor. In two of the rats, we have also collected MRIET data with rms currents of 0.5, 1 and 2mA. Highly consistent results were seen especially between 1 and 2mA cases. For example, when MREIT images of 1mA and 2mA cases were subtracted, the mean of the residual was only 1.3% of the mean conductivity in the whole slice. In the case of 0.5mA vs 1mA, the mean of the residual was 12%.

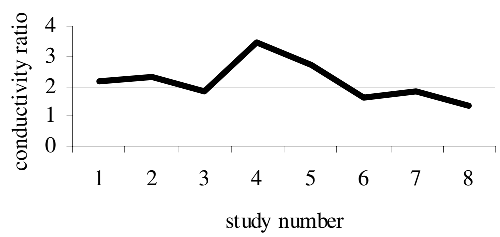

Fig.2. The ratio of mean conductivity in the tumor versus the rest of the body over eight *in vivo* studies.

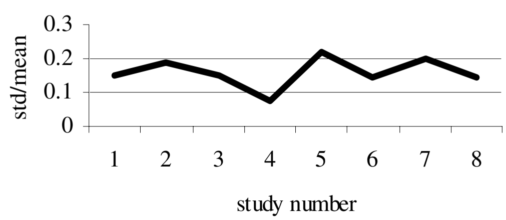

Fig.3. The ratio of standard deviation of conductivity versus its mean in the tumor in eight *in vivo* studies.

In this study, it has been demonstrated that MRI based impedance imaging has the potential to investigate malignant tumors *in vivo*. At this stage the technique may not be used as a standalone diagnostic tool; but it could provide useful information in characterizing the tumor, once a suspicious lesion is detected by other methods to improve specificity. Physiological and structural changes in tumors that lead to such changes in conductivity will be investigated in future studies. Note that good quality MREIT images were collected with biologically safe electrical current levels.

References: [1] Malich A. *et al, Clinical Radiology*,56:278-283, 2001; [2] Silva J.E.D et al.*Med. Biol. Eng. and Comp.*, 38:26-30, 2000; [3] Muftuler LT *et al TCRT* v 3 (2), 599-610, (2004); [4] Muftuler LT et al *Proceedings of ISMRM* 2005, p 2356.

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