Electromagnetic Tissue Property Mapping in Cancer Imaging

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Use of electromagnetic tissue properties for cancer detection has been explored by several research groups for almost half a century. Jossinet studied impedance and admittance of freshly excised breast tissues between 488Hz and 1MHz [Physiol. Meas. 19: 61-75, 1998] and reported that the impedance of normal tissues and benign pathologies were similar while the impedance of carcinoma was substantially higher at lower frequencies. Blad and Baldetorp studied electrical properties of tumors between 1.5kHz and 700kHz and demonstrated that the spectral characteristics of tumors and muscles tissues were significantly different. Based on these and several other in vitro studies, scientists developed Electrical Impedance Tomography (EIT) systems to study impedance properties of breast cancer. These systems inject current into the tissues and reconstruct conductivity images from the voltage measurements on the boundary. For instance, Cherepenin et al [Physiol. Meas. 22, 9-18, 2001] and Osterman et al [Physiol. Meas. 21:99–109, 2000] developed EIT systems for breast cancer screening, which produced images in which there was strong contrast between tumors and healthy tissues. Multi-frequency EIT images revealed that the contrast produced by the tumors was more prominent in permittivity images compared to conductivity images. Similar finding were reported by Malich et al [Clin. Radiol., 56, 278-83, 2001] in which they used an Electrical Impedance Scanning (EIS) system for breast cancer imaging, which is similar to an EIT system. Studies of electrical properties of tumors were not restricted to low frequencies and several researchers studied cancer imaging at microwave frequencies [Bindu et al, PIER 58, 149–169, 2006]. Initial reports with tissue samples produced promising results showing clear discrimination in terms of dielectric permittivity. More recently MR based EIT (MREIT) has been introduced, in which weak electrical currents are injected into the tissue and resulting perturbations in the magnetic flux density are measured using phase information in MR images [Woo et al, SPIE 2299:377–85, 1994; Birgul O., et al PMB, 48:3485-3504, 2003;]. Various techniques have been proposed for DC [Scott et al, IEEE TMI 10:362-374, 1991], AC [Ider, et al IEEE TMI 16:617-622, 1997], and RF [Scott et al, IEEE TMI 14:515-524, 1995] currents. Unlike EIT, the spatial resolution in the MREIT is position independent. However, it should be noted that only the component of the magnetic flux density in the direction of the main field of the MRI system can be measured. Therefore, one must develop techniques to solve the inverse problem of finding the conductivity or current density from only one component of magnetic flux density. With MREIT, only the relative conductivity values can be reconstructed from the magnetic flux density measurements. In order to find the absolute conductivity values, at least one voltage measurement from the boundary is required.

Our group [Muftuler et al, TCRT 5:381-7, 2006] and others [Lee et al, PMB. 51:443-55, 2006; Kovalchuk, Ph.D dissertation, USF 2008] explored the feasibility of breast cancer imaging using MREIT (Fig.1). In our studies we first investigated the robustness and accuracy of the reconstruction techniques, contrast and resolution [Muftuler et al, PMB. 51:5035-49, 2006]. We demonstrated that objects as small as 1mm apart could be resolved in phantoms. On the other hand, the technique was not very sensitive to small contrast changes. While we could clearly distinguish objects that had twice the conductivity of the background, 15% change in conductivity was barely visible. Accuracy of the technique was also demonstrated by a time-lapse imaging study of a gel phantom (4mM CuSO4, 2% agarose) with an inner structure that was doped with an additional 0.83% NaCl (20 times higher conductivity relative to the background). Sodium diffusion over time from this inner structure to outer low concentration areas could be clearly observed and the measurements matched the theoretical calculations. Another technique that helped improve the accuracy of conductivity images was to incorporate structural information obtained from conventional MRI data into the reconstruction. Data from either T1w MRI or Apparent Diffusion Coefficient from DWI or Sodium images were used in MREIT reconstruction while maximizing the mutual information between the conductivity image and the corresponding MR image. Finally, we conducted MREIT experiments on phantoms at biologically safe current levels (100μA-200μA) so that it could be safely used on live animals and humans.

Fig.1. T2w and MREIT images of two animals with R3230AC tumors. T2w scans are displayed above and corresponding MREIT images are depicted in color right below. Tumor areas are encircled. Bright objects outside the animals’ body were markers to identify exact location of electrodes.