MREIT and EPT: a comparison of two conductivity imaging modalities

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Introduction Magnetic resonance electrical impedance tomography (MREIT) [1] and MR electrical properties tomography (MREPT) [2] are medical imaging modalities capable of visualizing electrical permittivity and conductivity distributions of electrically conducting objects; MREIT provides conductivity images at the low frequency range below 10 kHz by post-processing phase images subject to externally injected currents, while MREPT provides admittivity (complex permittivity) images in the range of 10-200 MHz by post-processing B1 maps obtained by using a standard RF coil of an MR system. Here, we present a distinct difference between MREIT and MREPT in terms of conductivity images using phantom experiments.

Theory and Methods For MREPT phantom experiments, there exist reconstruction errors in evaluating the absolute admittivity due to the incomplete data; the reconstruction algorithm of MREPT requires knowledge of the magnetic field H = ($H^+(\mathbf{r})+H^-(\mathbf{r}), -iH^+(\mathbf{r})+iH^-(\mathbf{r}), 0$) corresponding to MR system's positive and negative polarized RF fields. From Maxwell's equation, the admittivity can be divided into two terms (Eq. 1) where γ* is defined as the terms obtained from local homogeneous regions and β represents the residual terms (Eq. 2). Therefore, for local regions having a low conductivity contrast, Eq. 3 can be used [3,4].

$$\sigma(\mathbf{r}) + i\omega\varepsilon(\mathbf{r}) = \frac{\gamma^*(\mathbf{r}) + \beta(\mathbf{r})}{i\omega\mu} \quad \text{Eq.1}$$

$$\gamma^*(\mathbf{r}) := \frac{\nabla^2 H^+(\mathbf{r})}{H^+(\mathbf{r})} \qquad \beta(\mathbf{r}) = \left(\nabla^2 H^-(\mathbf{r}) - \gamma^*(\mathbf{r})H^-(\mathbf{r})\right)\left[H^+(\mathbf{r})\frac{\partial H^+}{\partial z}(\mathbf{r}) - H^-(\mathbf{r})\frac{\partial H^-}{\partial z}(\mathbf{r})\right]^{-1}\frac{\partial H^-}{\partial z}(\mathbf{r}) \quad \text{Eq.2}$$

$$\sigma(\mathbf{r}) + i\omega\varepsilon(\mathbf{r}) \approx \frac{\nabla^2 H^+(\mathbf{r})}{i\omega\mu H^+(\mathbf{r})} \quad \text{Eq.3}$$

Phantom experiments were conducted to show distinct features of MREPT versus MREIT. First, an MREPT experiment was performed to validate the conductivity measurement using Eq. 3. NaCl doped phantoms with varying conductivity values (2%, 4%, and 6% NaCl) were built and tested. A double angle method (DAM) for B1 amplitude and phase measurement was used for all MREPT experiments (TR/TE 600/20ms, quadrature transmit/receive coil). Second, a comparison study of MREIT and MREPT was performed. Agar phantoms with different conductivity values were built and tested. Two experiments were performed: one with a transparency film without any holes surrounding the agar objects (objects A and B in Fig. 2a) and another experiment with the same transparency film but with holes. In doing so, the film without hole serves as an insulator for the MREIT experiment, while for the MREPT experiment, it can be viewed as a capacitive material and thereby produce admittivity contrast. In case of the film with holes, a finite conduction current is expected to flow into the agar object producing conductivity contrast in MREIT. For MREIT, a spin echo based Bz field mapping sequence was used for conductivity image reconstructions [5]. All experiments were conducted on a 3T scanner.

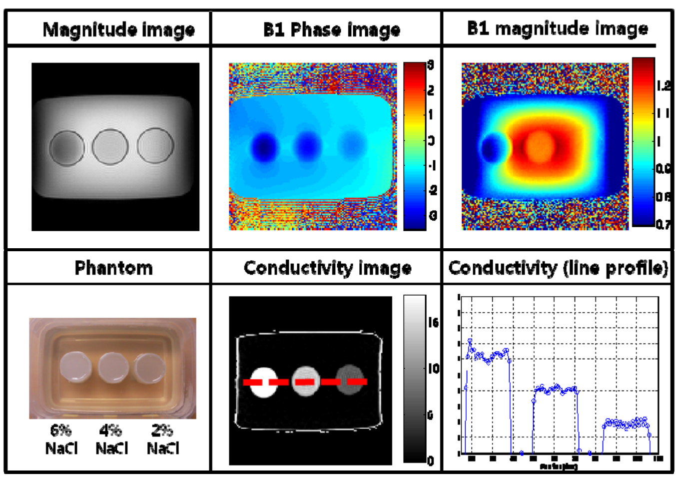

Figure 1. MREPT experiment

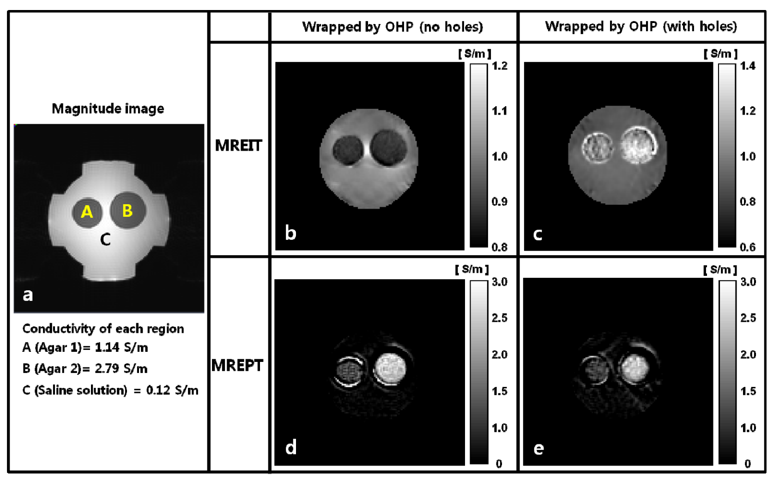

Figure 2. MREPT vs. MREIT experiment

Results and Discussion Figure 1 shows results of the MREPT experiment. Both the magnitude and phase information were used for producing the conductivity image. However, conductivity is mainly influenced by the phase information of B1 while permittivity is mostly dominated by the magnitude information of B1. Dedicated pulse sequences to acquire accurate phase information can be useful. In Fig. 2, results from MREIT and MREPT experiment are shown. As seen, for MREIT, the film without hole restricts any current flow into the agar object and therefore results in almost zero conductivity. However, in the presence of holes in the film, a current flow is enabled and we can reconstruct finite conductivity values. The apparent conductivity is related to the shape and size of these holes. However, for MREPT, since the operating frequency is at 128 MHz, the thin film behaves as a capacitor and displacement currents flow through the wrapped agar object. Therefore, the conductivity measured inside the wrapped agar object is the same regardless of the presence of holes in the film. This experiment shows the distinct difference of MREIT and MREPT in terms of admittivity imaging and can be supplementary to each other since they provide information at different frequency bands. Additional experiments involving measurements of conductivity (complex permittivity) in human tissues using MREIT and MREPT can potentially provide useful clinical information.

References [1] Woo et. al., SPIE 1994, p377 [2] Katcher et. al., IEEE Trans Med Imag 2009, 28;p1365 [3] Wen, SPIE 2003, p471 [4] Haacke et.a l., PMB 1991, p723 [5] Seo et. al., IEEE Trans Med Imag 2008, 27:p1754.