Application of IDEAL for the Correction of Chemical Shift Artifacts in MREIT

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Introduction

Several *ex vivo* studies have reported that the electrical impedance of malignancies is lower than healthy tissues and benign formations [Malich *et al*, Eur Radiol 10:1555-61 (2000)]. Therefore, *in vivo* conductivity imaging may have potential applications in tumor diagnosis. Magnetic resonance electrical impedance tomography (MREIT) is an emerging, non-invasive conductivity imaging modality in which electrical currents are injected into an object, the resulting magnetic flux density distribution is measured using MRI, and these MRI measurements are then used to reconstruct the conductivity distribution within the object.

Only a very limited number of *in vivo* MREIT studies have been reported. Obstacles limiting *in vivo* application include restrictions on the maximum (safe) level of injected currents, motion artifacts, and chemical shift artifacts. With chemical shift artifacts, the location of fat tissues appear shifted along the readout direction, which results in a distortion of the phase maps utilized in MREIT. Use of low readout bandwidths for improving the SNR when using lower injected current levels further magnifies these artifacts.

In this study, we corrected for chemical shift artifacts in order to generate accurate phase maps for use in MREIT. The iterative decomposition of water and fat with echo asymmetry and least-squares estimation (IDEAL) technique [Reeder *et al*, Mag Res Med 51:35-45 (2004)] was appropriately utilized to generate separated water and fat phase maps. The fat images were corrected for chemical shift and recombine with the water images to generate the total corrected phase maps. These phase maps were then used to reconstruction the conductivity distribution.

Methods

For the test phantom, a hollow acrylic disk with an inner diameter of 7 cm and thickness of 2 cm was filled with 2% agarose and 10 mM $CuSO_4$. Within this disk, a smaller cylindrical shell of 12mm diameter was placed slightly off-center and filled with vegetable oil (Fig. 1). The plane of the phantom was placed perpendicular to the main static MRI field (z-direction). Three copper electrodes each 3 mm wide were placed equidistant along the inner acrylic wall and used to inject currents into the interior region.

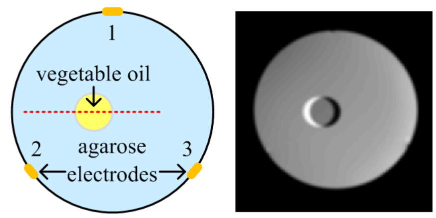

Fig. 1. *Schematic and MR magnitude image of the phantom*

Data was collected using a 4 T MRI system. A 2 mA bipolar current pulse was injected into the phantom and the resulting z-component magnetic flux density distribution B_Z was measured using a modified (asymmetric) spin-echo pulse sequence [Scott *et al*, IEEE TMI 10:362-374 (1991)] as diagramed in Fig. 2. A group of three data sets was acquired with the position of the 180 degree pulse shifted by 0, τ, and -τ (τ = 420 µs). In general, the IDEAL algorithm is capable of processing data with arbitrary time shifts. A second group of data was acquired with the polarity of the injected current waveform reversed. Common scan parameters were: TR = 500 ms, TE = 50 ms, $T_A+T_B = Tc = 44$ ms, BW = 20 kHz, FOV = 10 cm, matrix = 128 x 128, slice thickness = 5 cm, NEX = 2.

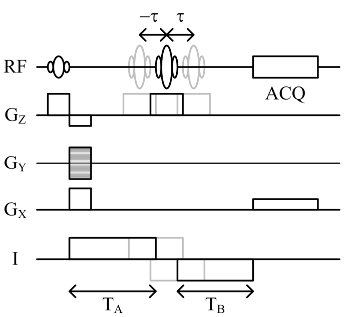

Fig. 2. *MREIT pulse sequence*

Processing of the raw MRI data is outlined in Fig. 3. Separated (complex) fat/water images were generated using the IDEAL algorithm with appropriate application to allow for preservation of the phase information. Separated fat/water B_Z maps were then determined from the argument of these images. The fat B_Z maps were corrected for chemical shift and recombined with the water B_Z maps to generate the total corrected B_Z map. Two B_Z maps (B_{12}, B_{13}) were calculated using electrode pairs 1&2 and 1&3 respectively for current injection, and used simultaneously in the conductivity reconstruction. To reconstruct the conductivity distribution using the MRI measurements, the iterative sensitivity matrix method (SMM) with Tikhonov regularization was utilized, where the relationship between conductivity and magnetic flux density is linearized around an initial conductivity (i.e. uniform distribution) and formulated as a matrix equation [Birgul *et al*, Phys Med Biol 51:5035-5049 (2006)].

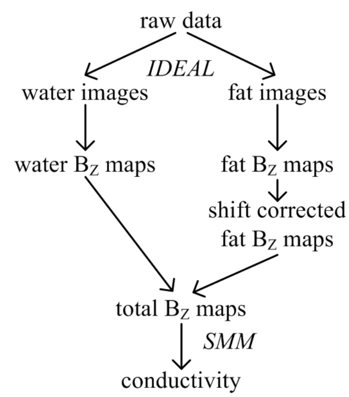

Fig. 3. *MREIT data processing*

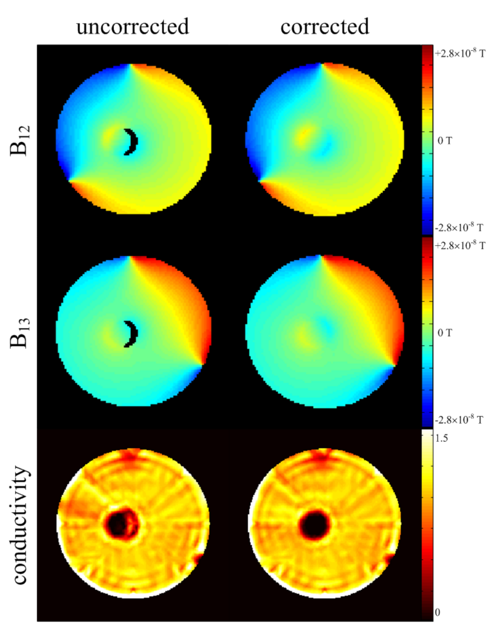

Fig 4. *Uncorrected and corrected images*

Results

Separation of the water and fat images was accomplished using the previously outlined IDEAL technique. Relative conductivities were reconstructed from the B_Z maps using 10 iterations of the SMM. The profile of the conductivity reconstruction across the red dotted line of Fig. 1 is shown in Fig. 5.

Discussion

Inspection of Fig. 4 reveals that chemical shift artifacts both distort the B_Z maps and leave a region of signal void. Consequentially, the resulting conductivity reconstruction suffers, as also seen in Fig. 5. Through appropriate application of the IDEAL algorithm, B_Z maps free of chemical shift artifacts were generated, resulting in an improved conductivity reconstruction.

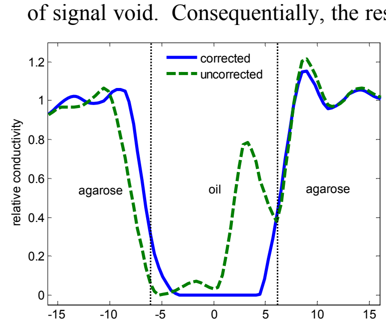

Fig. 5. *Conductivity profiles*

The results of this study demonstrate that chemical shift artifacts can adversely affect the accuracy of MREIT, and that appropriate application of the IDEAL technique can alleviate this problem. Correction of chemical shift artifacts in MREIT will be crucial in future *in vivo* studies, particularly when imaging regions with large fat content such as the breast.

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