Simultaneous Electromagnetic Property Imaging using multiecho gradient echo

Dong-Hyun Kim[1], Sung-Min Gho[1], Narae Choi[1], and Chunlei Liu[2]

[1]*Electrical and Electronic Engineering, Yonsei University, Sinchon dong, Seoul, Korea, Republic of,* [2]*Brain Imaging and Analysis Center, Duke University, Durham, NC, United States*

Introduction MRI has shown to be able to quantify both magnetic (e.g. quantitative susceptibility mapping, [1]) and electrical (e.g. conductivity mapping [2]) property. The motivation to perform 'electromagnetic (EM)' property imaging has both research and clinical interests. Current studies normally perform one of the above methods individually. Being able to simultaneously quantify both susceptibility (χ) and conductivity (σ) mapping can be useful since misregistration can be alleviated due to separate measurements. Previous reports have shown that conductivity can be obtained using phase values obtained at TE=0 [3]. Susceptibility, on the other hand, can be measured via the phase evolution obtained after TE=0 (i.e.,TE>0) using e.g. gradient echo (GRE) sequences. Here, we introduce a simultaneous susceptibility and conductivity quantification method. Using a multiecho GRE sequence, the phase of the spins at TE=0 can be retrieved providing conductivity information while the subsequent phase evolution can be used for susceptibility mapping.

Theory and Methods The RF field used for spin excitation is established within the object, whose distribution is determined by the Maxwell equation. Here, the admittivity of the object modulates the RF field, i.e., the magnitude and phase distribution at TE=0 can be considered to be established within the object that is determined by the admittivity distribution. Subsequently, spins interact with this RF field, producing the signal in MR. This process is governed by the Bloch equation. The evolution of the magnitude and phase of the spins here is determined by the macroscopic and microscopic field inhomogeneity, which is highly correlated with the susceptibility distribution. We assume motion and other phase effects to be negligible.

A multiecho GRE sequence was used to examine the capability of performing simultaneous electro- and magnetic property imaging. First, simulations were performed to identify the phase profile at TE=0 due to admittivity and its effect on susceptibility quantification. An EM simulation software was used (REMCOM) to determine the phase profile at TE=0 for a three cylinder phantom model (Fig. 1). Additional phase accrual after TE=0 were generated by assuming a spatial distribution of $\chi(r)$ using a Fourier domain approach [4].

We also acquired data using a multiecho GRE sequence (3T, TR/TE = 350/4.15 ms, # of echoes = 6, echo spacing = 3.55 ms, BW = 391 Hz/Pixel, FA = 30^o, matrix size = 128x128x72). Three phantom cylinders mixed with NaCl and gadolinium (Gd) were built (Fig. 2). Phase values for TE=0 were retrieved by using a linear extrapolation of the multiecho data. Conductivity was determined using the approach provided in [3]. Susceptibility was determined using a direct voxel by voxel division approach [5].

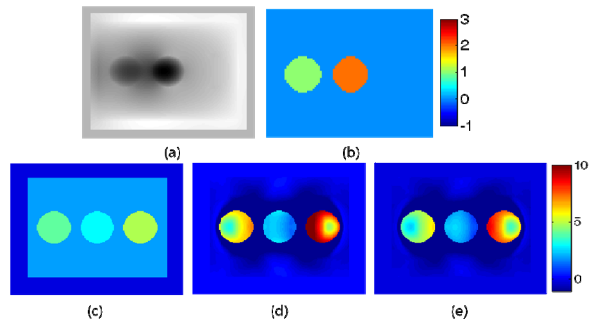

Figure 1. Simulation results. (a) Simulated phase at TE=0 (b) The assumed conductivity map of the simulated phantoms (left: 1 S/m, center: 2 S/m, right: 0 S/m) (c) The assumed susceptibility map (left: 4 ppm, center: 3 ppm, right: 5 ppm) (d) Estimated susceptibility map using GRE phase without TE=0 phase removal (e) Estimated susceptibility map using GRE with phase value at TE=0 removed.

Results and Discussion Figure 1 shows results of the simulation. It is shown that phase at TE=0 is highly related to the electrical properties. For conductivity values on the order or ~1 S/m and 5 cm size objects, the phase difference over this object is on the order of 0.5 radians (~30^o). In general, the phase distribution is the result of Helmholtz equation for homogeneous regions. Quantitative susceptibility mapping shows that removal of this TE=0 phase (Fig. 1e) gives better delineation of the true value. The resulting susceptibility value before and after phase removal for the three cylinders were 3.7/4.0 (left), 1.5/2.2 (center), and 5.2/5.1 (right) ppm.

Figure 2 shows the results obtained from the phantom study. In Fig. 2d, the conductivity map is provided. Quantitative value obtained was 0.88±0.45 (left), 0.08±0.37 (center), 1.44±0.42 (right) S/m. Measurement values using a conductivity meter gave 0.86 (left), 0.02 (center), and 1.5 (right) S/m. The relative susceptibility values obtained in Fig. 2f were 0.64±0.15 (left), 0.62±0.06 (center), and 0.64±0.09 (right) ppm.

Our results show that simultaneous EM property imaging is feasible. A multiecho gradient echo sequence can be used to retrieve phase values at TE=0 which can be used to determine the conductivity. The other phase values subsequently can be used to determine the susceptibility. In susceptibility processing, removal of phase values at TE=0 is recommended. Alternatively, phase retrieved by field mapping approach is desirable. From the phantom experiments, it is seen that conductivity processing suffers from noise. As for susceptibility processing, the absence of information in the cone shaped k-space region results in streak artifacts. For both, advanced processing methods seem inevitable.

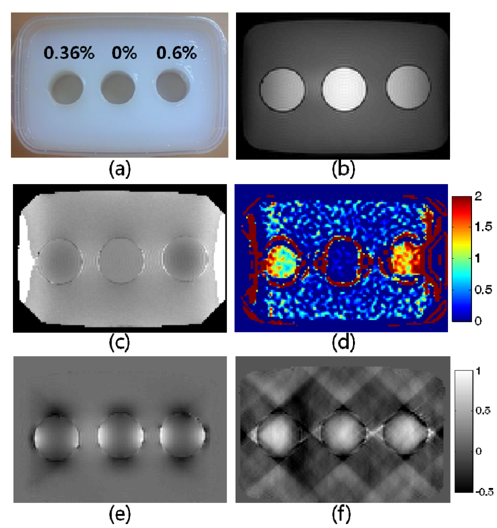

Figure 2. (a) Phantom design (Three cylinders have same Gd concentration of 0.5%, with NaCl concentrations as noted) (b) Magnitude image (c) Interpolated phase image at TE=0 (d) Conductivity map (e) Estimated phase induced by susceptibility component only (i.e. with TE=0 phase removal) (f) Susceptibility map using phase from (e).

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