Comparison of Multi-slice Current Density Imaging in SE and GE: Phantom Experiment

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ABSTRACT: Current density imaging (CDI) is a modality of magnetic resonance imaging that enables electric current distribution imaging in conductive samples. Two different sequences, spin- echo (SE) and gradient echo (GE), were used to measure the 3-D current density inside a cylindrical phantom. In comparison to SE sequences, the GE images show a higher radial distribution of current density around the center of the phantom except for slices at larger distance from current blocker plate where a uniform distribution was observed.

INTRODUCTION: Since biological tissues have different electrical properties it is possible to obtain anatomical and functional information from CDI. Low Frequency Current Density Imaging (LF-CDI) [1] uses MRI to measure the magnetic fields produced in an object using an applied current. Once spatial maps of magnetic fields, which are encoded in phase images, are obtained, the electric current density values at every pixel can be calculated by using the following equations.

$$B_J = \frac{\varphi}{\gamma T_c} \quad (1), \qquad \boldsymbol{J} = \frac{1}{\mu_0}\left[\left(\frac{\partial \boldsymbol{B_z}}{\partial \boldsymbol{y}} - \frac{\partial \boldsymbol{B_y}}{\partial \boldsymbol{z}}\right)\boldsymbol{i} + \left(\frac{\partial \boldsymbol{Bx}}{\partial \boldsymbol{z}} - \frac{\partial \boldsymbol{B_z}}{\partial \boldsymbol{x}}\right)\boldsymbol{j} + \left(\frac{\partial \boldsymbol{By}}{\partial \boldsymbol{x}} - \frac{\partial \boldsymbol{Bx}}{\partial \boldsymbol{y}}\right)\boldsymbol{k}\right] \quad (2)$$

Where φ is phase, T_c is the width of current pulse and γ is the gyromagnetic ratio. Equation (2) indicates that three orthogonal orientations of the subject must be acquired [1]. The current density distribution in tissue depends on different factors such as: injection current, electrode configuration, shape of the object and conductivity distribution inside the subject. This paper describes experimental results of current density distributions for two sequences: spin- echo (SE) and gradient echo (GE).

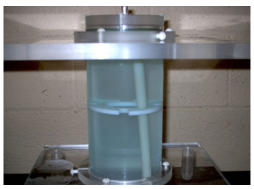
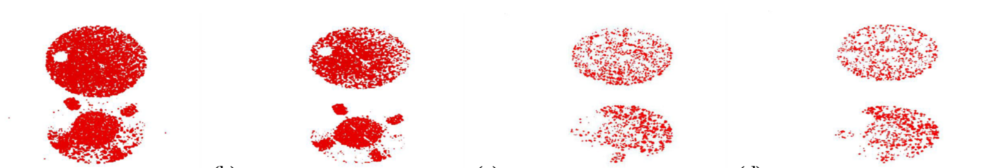


Fig. 1: Cylindrical Phantom



(a) (b) (c) (d)

Fig. 2: Images of first and last slices of (a) J_{total}, (b) J_z, (c) J_x, (d) J_y for SE.

METHODS: Fig. 1 shows a cylindrical phantom with two copper surface electrodes on top and bottom to inject current through the conductive solution inside the cylinder. To generate a non-uniform current distribution inside the phantom a plastic current blocker plate near the center is inserted [2]. To distinguish between different slices, a locator rod is inserted along a diagonal axis. CDI was implemented on a GE Horizon LX 1.5T imager, using modified SE and GE sequences. A bipolar current is pulsed synchronously with the standard SE sequence and applied between $\mathbf{90^{o}}$ and $\mathbf{180^{o}}$ RF pulses while in GE a unipolar current is applied after 90^{o} RF pulse. Phase cycling is applied to remove any systematic error that arises from constant phase terms. The pulse repetition time 1000 ms and echo time 90 ms for both SE and GE were selected. The amount of injection current was 130 mA with a width of 76 ms. Ten slices (2 mm thickness) were acquired using 256x256 resolution at 32 cm FOV.

MR phase images from different slices contain geometrical distortion due to the inhomogeneity of the main magnetic field and the gradient field nonlinearity. 3D- CDI requires registration of three phase images sets related to three orthogonal orientation of a subject. To measure distortion the same phantom containing 70 long tubes filled with water (3mm diameter) equi-spaced on 3 circles, were used. By finding the centers of each circle in three orientations we applied a geometrical error correction by using least square method.

(a) (b) (c) (d)

Fig. 3: Images of first and last slices of (a) J_{total}, (b) J_z (c) J_x, (d) J_y for GE

RESULTS: Fig. 2 and 3 show images of the current density distribution for the total current density (J_{total}),J_z, J_x and J_y for first (bottom) and last (top) slices in SE and GE sequences respectively. Slice 1 starts just above the current blocking plate and subsequent slices are taken upward from that point at 2mm interval.

CONCLUSIONS: Current densities directed along z-axis have the highest components in all slices for SE and also GE. Radial densities J_x and J_y in GE are higher than in SE which shows a larger radial distribution of current from the center of phantom in GE. The features of the current blocking plate can be better recognized in slice 1 of the SE images. The total current density in the last GE slice has a more uniform distribution than in the SE sequence, which indicates a more uniform density in GE. The GE images show that phase images in GE are more sensitive to the main magnetic field inhomogeneity. Future study will include a new geometrical error correction for GE.

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