Experimental Testing of Radio Frequency Current Density Imaging with a Single 180-degree Rotation

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Introduction

Previously implemented radio frequency current density imaging (RF-CDI) techniques can evaluate the component of the injected Larmor frequency current density in the direction of the static magnetic field $\mathbf{B}_0$ only under the single orientation assumption [1]. However, this assumption can be easily violated because it requires the current to flow mainly in the direction of $\mathbf{B}_0$ unless specific symmetry exits. We recently proposed a new reconstruction method based on one 180-degree rotation to fully recover one component of the current density [2]. The purpose of this work is to verify the new method by experiments.

Theory

The theory of RF-CDI stems from the generalized Ampere's law. The magnetic field produced by the current in a plane transverse to $\mathbf{B}_0$ (by convention, the *z* direction) can always be divided into a left circularly polarized (LCP) component and a right circularly polarized (RCP) component with respect to $\mathbf{B}_0$. Only the LCP component contributes to the resonance of magnetization [3] and hence can be measured by imaging. In general, the RCP component is also required to reconstruct J_z. However, under the single orientation assumption $|\partial H_z / \partial z| << |J_z|$, J_z can be evaluated from the measured LCP component ($\tilde{H}_x, \tilde{H}_y$) by

$$J_z = 2\left(\frac{\partial \tilde{H}_y}{\partial x} - \frac{\partial \tilde{H}_x}{\partial y}\right) + 2j\left(\frac{\partial \tilde{H}_x}{\partial x} + \frac{\partial \tilde{H}_y}{\partial y}\right). \qquad (1)$$

Now consider rotating the sample 180 degrees as illustrated in fig. 1. The original RCP component becomes the LCP component after the rotation. Therefore, with these two orientations, J_z can be calculated by

$$J_z = \left(\frac{\partial \tilde{H}_y^0}{\partial x} - \frac{\partial \tilde{H}_x^0}{\partial y} - \frac{\partial \tilde{H}_y^\pi}{\partial x} - \frac{\partial \tilde{H}_x^\pi}{\partial y}\right) + j\left(\frac{\partial \tilde{H}_x^0}{\partial x} + \frac{\partial \tilde{H}_y^0}{\partial y} - \frac{\partial \tilde{H}_x^\pi}{\partial x} + \frac{\partial \tilde{H}_y^\pi}{\partial y}\right), \quad (2)$$

where superscripts 0 and π denote the two opposite orientations.

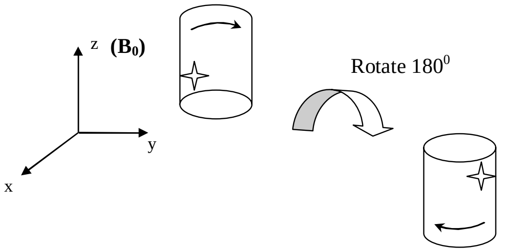

Fig. 1. Illustration of sample rotation in *yz* plane
The arrow on the cylinder represents a right circularly polarized component at the original position. It becomes left circularly polarized after the rotation.

Methods

To test the RF-CDI reconstruction by (2), RF-CDI experiments were performed on a tri-chamber phantom filled with conductive solutions. A numerical model resembling the phantom was also computed by FDTD as shown in fig.2 . The phantom was tilted with its axis 45 degrees with respect to $\mathbf{B}_0$ and data were acquired with the two orientations. J_z was computed by both the earlier approach (1) and the new method (2) and compared to the simulated results.

Results

Both the experimental and the simulation results shown in fig.3 indicate that $|J_z|$ calculated by (2) matches the expected one (fig.3. (a)), while $|J_z|$ reconstructed by (1) has a diagonal error pattern in the middle chamber.

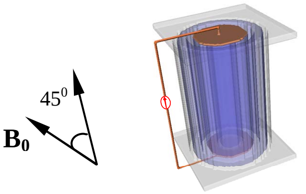

Fig. 2. A numerical model of the tri-chamber phantom used in experiments

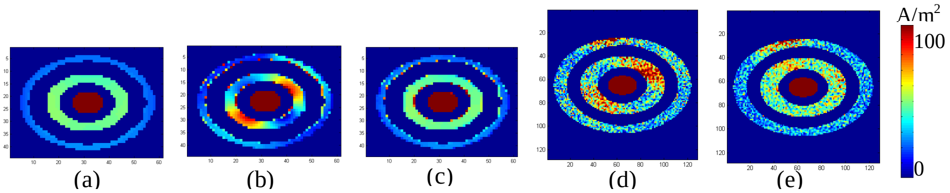

Fig.3 (a) Expected J_z magnitude. (b) Reconstructed $|J_z|$ by (1) for simulated data. (c) Reconstructed $|J_z|$ by (2) for simulated data. (d) Reconstructed $|J_z|$ by (1) for experimental data. (e) Reconstructed $|J_z|$ by (2) for experimental dada.

Discussion

It is straightforward to extend the method to determine all the components of the magnetic field $\mathbf{H}$ by another pair of 180-degree orientations perpendicular to the first pair. In fact, a single additional orientation suffices to provide enough information to determine H_z and hence to compute the current density vector field. Since the subject can remain in supine position in all the three required orientations, there would be no relative motions of organs and tissues among the orientations due to gravity. To implement the rotational schemes, the coupling effects of the sample and the imaging coil should be further investigated.

References:
[1]G.C. Scott et. al. IEEE Trans. Med. Imag. 14(3):515-524,1995. [2]D. Wang et. al. 6th NFSI&ICFBI: 341-344, 2007. [3] D. I. Hoult, Concepts Magn. Reson., vol.12, no.4: 173-187, 2000.