Magnetic resonance current density imaging without subject rotations

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Synopsis

Magnetic resonance current density imaging (MRCDI) is a useful tool to measure electrical current density inside a subject. Due to the requirement of subject rotations in conventional MRCDI, MRCDI has not been widely applied to *in-vivo* studies. In this work we propose a new current density imaging method by which a single component of the current density can be imaged without any subject rotations. We reconstruct the current density images in the spatial frequency domain using a spatial filter. Experimental results of a phantom study with a 3.0 Tesla MRI system are presented.

Introduction

It is important to know the current density distribution inside biological tissues when electric currents are applied to them for diagnostic or therapeutic purposes. Magnetic resonance current density imaging (MRCDI) is a useful tool to measure electrical current density inside a subject [1]. In MRCDI, three magnetic field components, B_x, B_y, and B_z, should be measured to calculate the current density vector $\boldsymbol{J}$. Therefore, we have to perform three different MRI experiments with subject rotations in MRCDI. Due to many problems caused by the subject rotations, the use of MRCDI has been limited to *in-vitro* small animal or plant studies [2]. In this work we propose a method for single current-density-component imaging without any subject rotations. Assuming that we are only interested in a certain component of $\boldsymbol{J}$ in the plane of interest, we propose a new current density image (CDI) reconstruction method. Experimental results of a phantom study with a 3.0 Tesla MRI system are presented.

Methods

Current density $\boldsymbol{J}$ can be derived by taking curls to the magnetic field $\boldsymbol{B}$, that is, $J = \nabla \times B / \mu_o$. Representing the curl operation and the divergence theorem, $\nabla \cdot J = 0$, in the spatial frequency domain, we can derive the following equation,

$$j_z = -\frac{i}{\mu_o} \frac{k_x^2 + k_y^2}{k_y} b_x \qquad [1]$$

where j_z is the Fourier transform of J_z, b_x is the Fourier transform of B_x, and k_x, k_y are the spatial frequencies in the x- and y-directions. Equation [1] implies that the z-component of the current density can be derived by applying the spatial filter, $(k^2_x+k^2_y)/k_y$, to the x-component of the magnetic field. In most biomedical applications in which two electrodes are contacted to the tissues to feed electrical currents, most of currents point to the direction from one electrode to the other. Therefore, one component measurement would suffice in most applications. Since the spatial filter kernel, $(k^2_x+k^2_y)/k_y$, is not defined on k_y=0, we estimated $j_z(k_x, k_y=0)$ by the polynomial interpolation technique after calculating all j_z values except on k_y=0. After calculating j_z, we reconstructed the current density image J_z through the inverse Fourier transform.

Results

In the first step to verify the proposed method, we made various finite element method (FEM) models of the conductivity distribution. Through FEM calculations, we have found that a single current component is dominating in the plane of interest that is apart from the electrodes even when the FEM model represents very inhomogeneous conductivity distribution. If we measure the magnetic field component in a plane as large as four times the current flowing region, the current density error due to the truncation effect is negligibly small. To experimentally verify the proposed method, we made a phantom as shown in Fig. 1. Through the two electrodes, we fed electric currents during the spin echo MRCDI experiments. The repetition time and the echo time were 300ms and 60ms, respectively, with the imaging matrix size of 128×128 and the slice thickness of 3mm. The current pulse width and amplitude were 48 ms and 27 mA, respectively. Figure 2(a) shows a current density image at the middle of the phantom. Figure 2(b) shows a cut view of the current density image along the dashed line. Due to the finite size of the magnetic field measurement, we have errors in the current density image. The L^2-error between the true and reconstructed current density images was 12.4%.

Conclusions

We have made images of a single current component without any subject rotations inside the MRI magnet. Even though small errors in the reconstructed current density are inevitable due to the truncation effect in the magnetic field measurement with MRCDI, we expect that the proposed method can be greatly used for current density imaging in animal or human subjects.

References

[1] Scott GC, et al., IEEE Trans Med Imag 1989; 10:2: 362-374.
[2] Sersa I, et al., Magn Reson Med 1997;37:404-409.

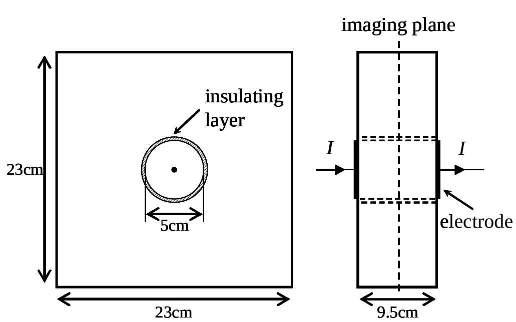

Fig.1 The phantom used in current density imaging.

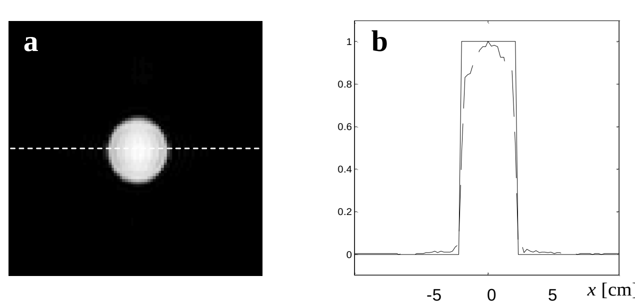

Fig. 2 (a) A reconstructed current density image and (b) a cut-view of the current density image along the dashed line (solid line: the true current density, dotted line: the reconstructed current density).