Effects of Limited Volume Coverage on Accuracy of MR-Electrical Impedance Tomography

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Introduction: The goal of this study was to investigate the effects of limited volume coverage on the accuracy of conductivity reconstruction in MR-Electrical Impedance Tomography (MREIT). Since the currents injected into an object will be distributed in the whole volume, limited volume coverage in data acquisition or reconstruction will impact the accuracy of resulting conductivity maps. On the other hand, the magnitude of current density will decrease rapidly as the distance from the injecting electrodes increases. Moreover, if one is interested in a particular volume of interest (VOI), the magnetic fields generated by currents away from the VOI could be negligible. Therefore, we investigated the decrease in magnitude of current density as the distance from the electrodes increases. We also investigated the contribution of these weaker currents to the magnitude of the magnetic fields generated within the VOI.

$$\nabla \cdot (\sigma \cdot \nabla \phi) = 0$$

$$\sigma \frac{\partial \phi}{\partial n} = \begin{cases} J \text{ on } (+) \text{ electrode} \\ -J \text{ on } (-) \text{ electrode} \\ 0 \text{ elsewhere} \end{cases} \quad (1)$$

$$\vec{E} = -\nabla \phi \qquad \vec{J} = \sigma \cdot \vec{E} \quad (2)$$

$$d\vec{B} = \frac{\mu_o I}{4\pi}\left(\frac{d\vec{l} \times \vec{R}}{R^3}\right) \quad (3)$$

Methods: In MREIT, weak electrical currents are injected into an object that generate magnetic fields, the z-component of which induces additional phase information in MR images. A modified spin-echo sequence was used with several π pulses applied during the zero-crossings of an alternating current and a phase shift accumulates, which is given in the final image as $\varphi(r) = 4\cdot\gamma\cdot N\cdot b_z(\mathbf{r})/\omega$, ($\gamma$: gyromagnetic ratio; N: # cycles of injected current; $b_z(\mathbf{r})$: the current-generated magnetic field at point r; ω: angular frequency of the injected current). Once $b_z(\mathbf{r})$ is calculated from the phase $\varphi(r)$ measurements, one can devise a method to calculate the conductivity map [*Muftuler LT et al TCRT v 3, 599-610, 2004*]. Since only the z-component of the magnetic field is used in MREIT, the transverse components of the current density, $J_x(\mathbf{r})$ and $J_y(\mathbf{r})$ are of interest. We performed several simulation studies to calculate the current density and magnetic fields inside a cylindrical volume (d=4.5cm h=7cm) with uniform conductivity distribution. Two electrodes were placed at 135^0 and 315^0 around the central transaxial slice (slice 0). First, the electric potential distribution was determined by solving the Poisson's equation with Neumann boundary value problem (Eq.1) using Finite Element Method (FEM). Here, σ is the 3D conductivity distribution and ϕ is the electric potential. The current density and the magnetic flux density are calculated using equations 2 and 3, respectively. In 3D FEM model 13773 nodes and 73452 of tetrahedral elements were used.

Results: Fig.1a shows the magnitude of the transverse current density $(J_x(\mathbf{r})^2 + J_y(\mathbf{r})^2)^{1/2}$ across 15 slices for regions labeled 13-19 in Fig.1b. $b_z(\mathbf{r})$ was calculated for five cases on these 15 transverse planes that were 5mm apart. For each case, the current density only within a transverse slab of various thicknesses was used for $b_z(\mathbf{r})$ calculations: ***case1***: 4.2cm, ***case2***: 3cm, ***case3***: 2.4cm, ***case4***: 1.8cm and ***case5***: 1.2cm. Fig.2 shows the $b_z(\mathbf{r})$ contour maps in slice 0. Fig. 2a is the resulting magnetic field when the transverse current density in 4.2cm thick slab was used (***case1***). Similarly, Fig.2b is the $b_z(\mathbf{r})$ for ***case5***. Fig.2c is the difference field when 2b is subtracted from 2a. When ***case1*** is taken as the reference, the field difference maps ($\Delta b_z(\mathbf{r})$) between ***case1*** and others give us a measure of the errors made in the calculation of $b_z(\mathbf{r})$ when the current density outside the selected slab is ignored. Therefore, we defined a region of interest (ROI) that encompassed the white contour band in the upper right hand corner of Fig.2c. The mean $b_z(\mathbf{r})$ inside the ROI for ***case1*** is taken as the reference and the mean of $\Delta b_z(\mathbf{r})$ for each case is calculated and divided by this reference mean. Results are summarized in table 1.

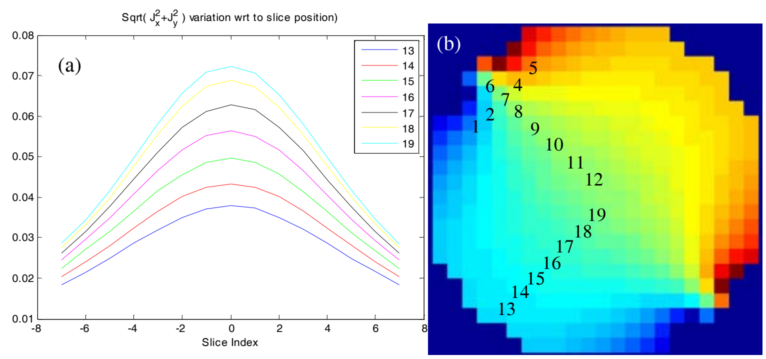

Fig.1. (a) magnitude of current density across slices in selected regions shown in the field map (b).

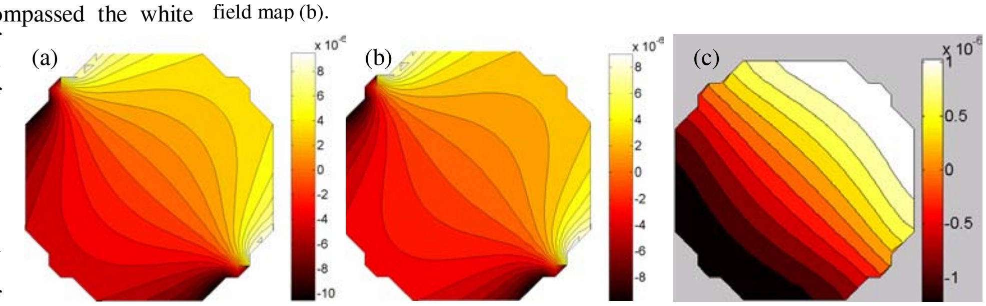

Fig.2. $b_z(\mathbf{r})$ contour maps for case 1 (a), case 5 (b) are illustrated. The difference of the two $b_z(\mathbf{r})$ maps is shown in (c). Current was injected between electrodes placed at 135^0 and 315^0.

Discussion: The result in Fig 1a shows that the current density in the plane that is 21mm away from the electrodes has significant magnitude. (e.g. in region 19, the magnitude of the current is roughly 40% of that of slice 0). Moreover, the magnetic field in the ROI in slice 0 is underestimated by almost 30% if only currents within a 12mm slab are taken into account. This will lead to underestimation of conductivity maps in this slice. Therefore, one has to acquire MREIT data that covers sufficiently large volume to obtain accurate conductivity maps. On the other hand, reconstruction of conductivity maps from large data sets may require 18-20 hours of computing time. Therefore, optimum volume coverage has to be found to obtain a balance between acceptable accuracy and computational efficiency by carrying out simulations and experiments. The preliminary results presented here were obtained from a uniform conductivity phantom. The results from objects of nonuniform conductivity will be different and models should be developed accordingly to find the optimum volume coverage for studies such as *in vivo* experiments.

	case5	***case4***	***case3***	***case2***
$100 * \dfrac{mean(\Delta bz(\mathbf{r}))}{mean(\boldsymbol{case1})}$	29	17	9	4.8

Table 1. Mean of $\Delta b_z(r)$ for each case divided by the reference mean

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