Calculation of Electromagnetic Field Distribution to Detect Liver Abnormalities using MR-based Electrical Impedance Tomography

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Target audience

The need for direct information on the electrical tissue properties of human is often and strongly felt among scientists and researchers who are involved in the interactions of electromagnetic (EM) fields and biological systems.

Purpose

In this study, we provided the simulation results of liver MREIT to evaluate the electromagnetic field distribution at three different electrode configurations using a three-dimensional realistic human abdomen model.

Methods

A three-dimensional abdomen finite element model was built using a reference CT data set (Fig. 1a). The reference images were segmented into significant abdomen components (liver, kidney, spinal cord, skin, fat, and muscle) and generated volumetric mesh (Fig. 1b and c). Conductivity values used in the models are recently measured values that were gathered in situations close to *in vivo* conditions. Three different electrode configurations representing the conventional, focused, and internal injection current were located around the boundary or inside the liver region (Fig. 1d to f). We used surface electrodes for both conventional and focused injection, a needle and surface electrode for internal injection. The electrode size was about $80 \times 80 \times 1$ mm^3 for surface and 2 mm diameter for needle electrode. The anomaly of 30 mm diameter inside the liver was inserted to evaluate the electromagnetic field distribution. Further details of the simulation methods followed by Sadleir *et al*.[1]

For the estimation of electromagnetic field, we solved for Laplace equation in our model. The induced voltage u in Ω satisfies the following boundary value problem with the Neumann boundary condition: $\nabla\cdot(\sigma(\mathrm{r})\nabla u(\mathrm{r})) = 0$ in Ω, $-\sigma\nabla u\cdot\mathbf{n} = j$ on $\partial\Omega$, where $\sigma(\mathrm{r})$ is the conductivity distribution within the abdomen $\partial\Omega$, $\mathbf{n}$ is a vector normal to the surface, j is the surface current density, and $\mathrm{r} = (x, y, z)$ is a position vector. The current density $\mathbf{J}$ is given by $\mathbf{J}(\mathrm{r}) = -\sigma(\mathrm{r})\nabla u(\mathrm{r})$ in Ω. The voltage solutions were computed on the abdomen domain, and then converted to magnetic flux density (B_z) values using the Biot-Savart law. MREIT technique uses the relationship between the measured B_z data and the current density $\mathbf{J}$ based on Ampere's law. $\mathrm{J}(\mathrm{r}) = (1/\mu_0)\ \nabla\times\mathbf{B}(\mathrm{r})$. To estimate the current density from the measured B_z data, we applied the projected current density method following the work of Park *et al*.[2] The data with a 500×500 mm^2 field-of-view, 128×128 matrix size, 1 mm slice thickness, and 100 slices in total was simulated.

Results and Discussion

Figure 2 shows the numerical simulation results of voltage (**V**, Fig. 2a), current density (**J**, Fig. 2b), and magnetic flux density (B_z, Fig. 2c) distributions in the liver region at three different electrode configurations. The calculation was performed with a single anomaly of 200% conductivity contrast inside the liver. The current was vertically injected with a 3 mA of amplitude and duration of 30 msec. From the resulting current density images in Fig. 2b, the internal injection method showed significantly higher current density distribution near the anomaly than the other methods due to the high current flow around the electrode. Comparing the results used in between surface electrodes, the focused injection showed two times higher current density than conventional injection. The B_z of internal injection also showed most enhanced signal intensity.

Figure 3 shows the profile of current density distribution at three different electrode configurations. Using the projected current density method, we can successfully image the current density from the B_z data of MREIT. The extremely high current density value around the anomaly was observed in the internal injection method. This primarily depends on the large amount of current flow around the electrode.

Conclusion

Electromagnetic field distributions, such as voltage, current density, and magnetic flux density, were imaged and compared to potentially detect liver abnormalities using MR-based electrical impedance tomography (MREIT).

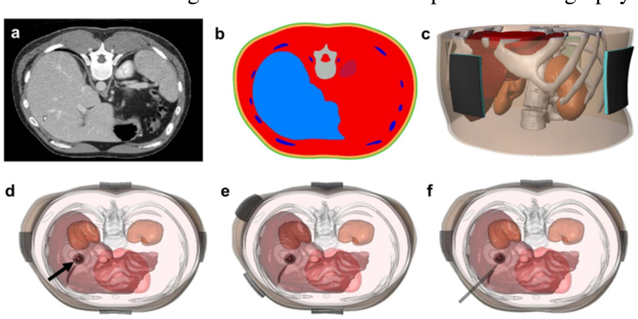

Fig. 1. Three-dimensional abdomen model for numerical simulation (a-c) and three different types of electrode configurations (d-f).

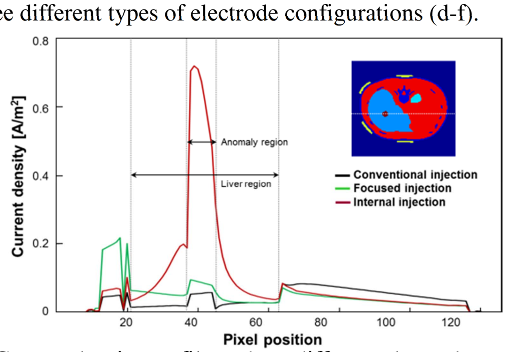

Fig. 3. Current density profile at three different electrode configurations.

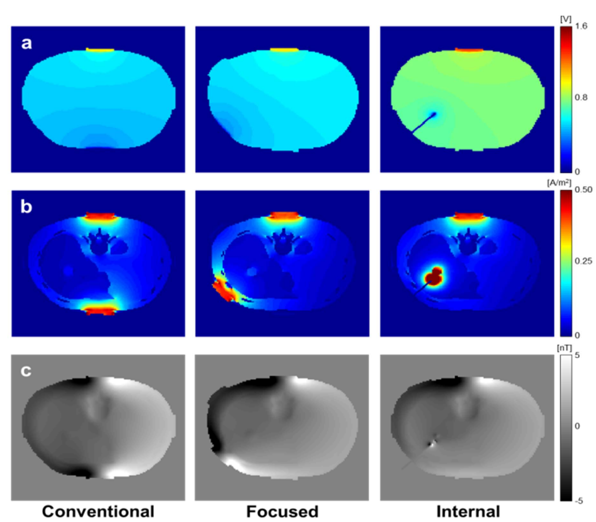

Fig. 2. Images of electromagnetic field distribution including voltage (a), current density (b), and magnetic flux density (c) from MREIT method.

References

1. Sadleir R, Sajib SZK et al. Simulation and phantom evaluations of magnetic resonance electrical impedance tomography (MREIT) for breast cancer detection. J Magn. Reson. 2013;230:40-49.
2. Park C, Lee BI et al. Analysis of recoverable current from one component of magnetic flux density in MREIT. Phys. Med. Biol. 2007;52:3001-3013.