Feasibility of Breast MREIT Conductivity Imaging for Cancer Detection: Experimental and Numerical Simulation Studies

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Purpose

The purpose of this study is to show a practical feasibility of MREIT conductivity imaging for the diagnosis of breast cancer through experimental and numerical simulation studies.

Materials and Methods

To evaluate noise levels in measured magnetic flux density (B_z) data, we conducted breast phantom imaging experiments using a 3T MRI scanner (Siemens Medical Solutions, Germany) with a multi-channel breast coil. We made an acrylic phantom of the thorax and breast (Fig 1a). After filling the phantom with saline of 0.12 S/m conductivity, two different biological tissues of porcine muscle and chicken breast were positioned in the phantom (Fig. 1b). We attached four carbon-hydrogel electrodes around the imaging area. Through two pairs of opposing electrodes, we sequentially injected currents I_1 and I_2 along two different directions. The ICNE pulse sequence was used with TR/TE = 800/20 ms, FOV = 180×180 mm^2, slice thickness = 4 mm, NEX = 10, matrix size = 128×128, number of slices = 7. After extracting B_z images from MR phase images, we estimate the noise level in measured B_z data (Sadleir *et al* 2005) and add this noise to simulation results.

We discretized the model in figure 1(c) into the finite element mesh in (d) including 319,753 tetrahedral and 44,263 triangular elements. We used the quadratic interpolation function and the total degrees of freedom was 2,985,532. We set the conductivity values of different tissues included in the model based on Gabriel *et al*. Using the MREIT simulator, we generated simulated data of voltages u_j, current densities $\mathbf{J}_j$ and magnetic flux densities $B_{z,j}$ for j = 1, 2. In the simulated $B_{z,j}$ data, we added Gaussian noise of proper standard deviation values. We used the single-step harmonic B_z algorithm implemented in CoReHA (conductivity reconstructor using harmonic algorithms) for multi-slice conductivity image reconstructions.

Results and Discussion

Figure 2 shows reconstructed conductivity images of the three anomalies with 10, 5 and 2.5 mm diameters depending on different numbers of NEX and current amplitudes. The conductivity images clearly demonstrate the advantage of a larger injection current amplitude and a larger number of averaging at the expense of an increased scan time. Since the total scan time may not be a critical limiting factor in breast imaging, we suggest increasing the number of averaging and reducing the current amplitude below 1 mA.

Figure 3 represents quantitative analysis of the average ΔB_z and noise levels of B_z depending on the different conductivity contrast and size of anomaly. The conductivity images with a pixel size of 3 or 4 mm may visualize an anomaly with 50% conductivity contrast and 5 mm diameter using 1 mA injection currents. Considering that conductivity values of cancerous tissues in the breast have much higher than 50% contrast compared with surrounding normal tissues, it is highly probable to distinguish an anomaly with a smaller than 5 mm diameter using 1 mA injection currents.

Conclusion

In this study, we found that breast cancer diagnosis using MREIT is feasible. Simulation results are promising to show that we can detect a cancerous anomaly in the breast while restricting the maximal current density inside the heart below the level of nerve excitation. Based on these findings, we plan to show the practical feasibility of breast MREIT and suggest future experimental studies on animal and human subjects.

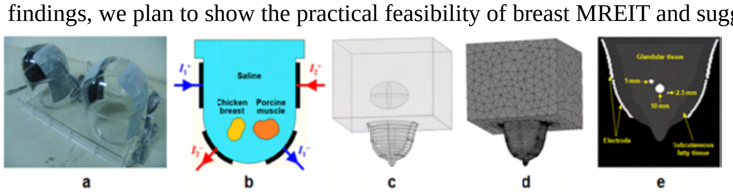

Fig. 1. (a) Three-dimensional breast phantom, (b) current injection method for imaging experiment. (c) Simulated breast model, (d) mesh, and (e) conductivity setting inside the breast region.

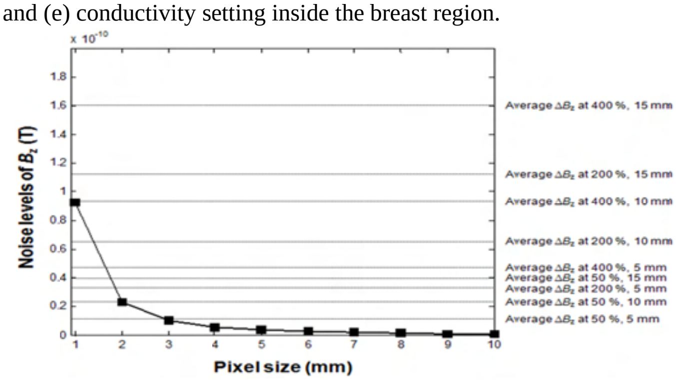

Fig. 3. Comparisons of the average ΔB_z with noise levels in B_z. The noise level was computed with total current injection time = 30 ms, NEX = 8, and slice thickness = 4 mm. We changed the conductivity contrast of the anomaly as 50, 200 and 400% and the diameter as 5, 10 and 15 mm. The amplitude of injected currents was 1 mA.

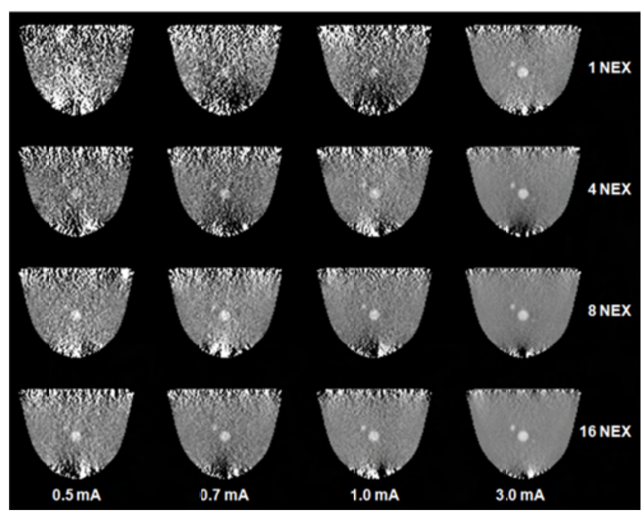

Fig. 2. Reconstructed conductivity images of the three anomalies with 10, 5 and 2.5 mm diameters using different numbers of NEX and current amplitudes.

References

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