EFFECT OF ANISOTROPY ON THE ACCURACY OF QUANTITATIVE CONDUCTIVITY IMAGING. A NUMERICAL STUDY

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Introduction

Most conductivity imaging methods assume isotropic electrical properties. Many soft tissues actually have anisotropic electrical properties, particularly those of cardiac muscles, skeletal muscles and nerve tissues. This paper is a simulation study comparing the effect of anisotropy on the results from two different types of conductivity imaging methods. The first, Diffusion Tensor Current Density Impedance Imaging or DT-CD-II is a method recently proposed [1] for reconstructing anisotropic conductivities. The second, Current Density Impedance Imaging or CDII [2] was designed to find an isotropic conductivity, based on measured currents. Both these methods require two Current Density Imaging (CDI) datasets (J_1 and J_2). The same simulated J_1 and J_2 were used in both cases.

The comparison is made using a validation approach [3] that requires a separate validation current density (J_3) [4] and a forward solver. The forward solver imports the internal impedance which is to be validated and the Neumann boundary conditions for J_3. This data is processed to compute the current J_{31} which would result from the conductivity obtained using the DT-CD-II method. The accuracy of the method is then determined by comparing J_{31} to the previously simulated J_3 (which in practice can be measured). This process is repeated, using the same J_3 and the impedance obtained using CDII, to calculate J_{32}. By comparing J_{31} and J_{32} to J_3 and to each other we can assess the accuracy of the two inversion methods.

Methods

We built a synthetic phantom with known conductivity and diffusivity based on a published diffusion MRI dataset. (Advanced Biomedical MRI Lab at National Taiwan University Hospital.) This data was acquired using 3T Trio Siemens MRI system. The voxel size is 2.9 mm x 2.9 mm x 2.9 mm, TR= 6200 ms TE= 118 ms, maximal b-value= 4000 s/mm^2.

The phantom model is shown in figure 1 which is a box with six electrodes distributed on four of its faces. The box is filled with synthetic anisotropic brain conductivity values estimated using the following equation [1].

$$\sigma(r) = c(r)D(r) \qquad (1)$$

Where $\sigma(r)$ is the conductivity tensor, $c(r)$ is the cross property factor and $D(r)$ is the corresponding diffusion tensor. The cross property factor as shown in figure 2 was approximated from a scaled magnitude image taking into consideration typical tissue conductivity values. A forward solver (COMSOL 4.4) is used to simulate current in three different orientations so that we can generate three different CDI datasets J_1, J_2 and J_3. As shown in figure 3, J_1 and J_2 are used to generate anisotropic conductivity using DTCDII and again to generate isotropic conductivity using CDII.

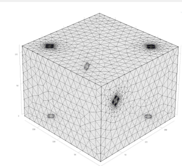

Figure 1. Model and mesh of the phantom with 6 electrodes on 4 of its faces.

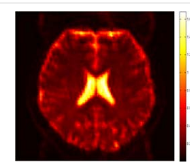

Figure 2. A slice of the simulated cross property factor used from a scaled magnitude image of the brain

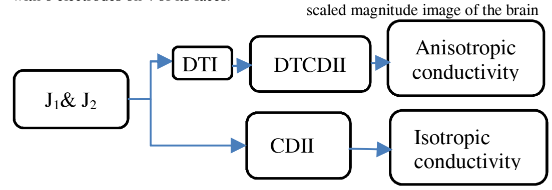

Figure 3. Phase I: Generation of the CDI data used by DTCDII and CDII to compute anisotropic and isotropic conductivities respectively.

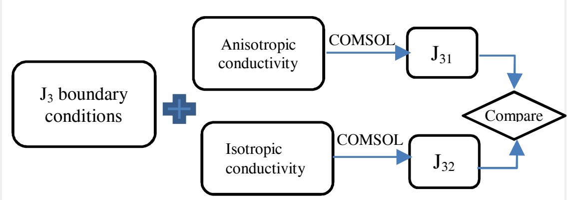

Figure 4. Phase II: Generation of the current density images using COMSOL and the isotropic conductivity or the anisotropic conductivities generated in phase I

Results

To evaluate the accuracy of each method the currents resulting from each reconstructed conductivity (J_{31} and J_{32}) are compared against the current J_3 from the known $\sigma(r)$ which is also used to determine the boundary condition (injected current) in the simulation. A mutual information based metric is used. Due to the interpolation process performed by the forward solver (COMSOL), intensity based metrics will not yield reasonable results. Accordingly, the Normalized Mutual Information NMI metrics were used [5]. NMI is defined by equation (2), where H_A and H_F are the marginal entropies of the two images to be compared, and H_{AF} is the entropy of the joint image histogram.

$$NMI = \frac{H_A + H_F}{H_{AF}} \qquad 1 \le NMI \le 2 \qquad (2)$$

Discussion

Figures 6 and 7 show that using NMI, the agreement between the current generated by DT-CD-II and the actual current surpasses that between current generated by CDII and the actual one. By using an anisotropic conductivity method results were more accurate. The proposed approach can be used to validate any isotropic or anisotropic conductivity imaging method. Since most current conductivity methods are hard to validate directly on complex objects possessing anisotropic conductivities this approach can be a robust and simpler alternative for most of the current impedance measurement techniques.

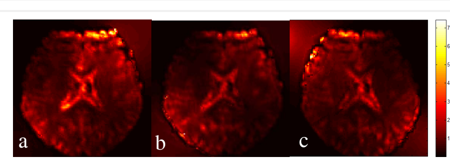

Figure 5. Magnitude of current density images of slice 22, where a, b and c are J_1, J_2 and J_3 respectively

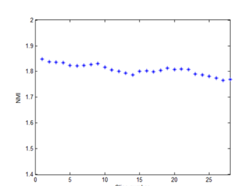

Figure 6. NMI between J_{31} and J_3

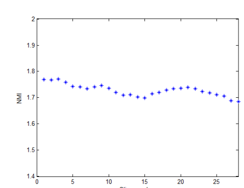

Figure 7. NMI between J_{32} and J_3

References

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