In Vivo Electrical Conductivity Tensor Images of Human Calf using DT-MREIT

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Target audience

The focus is to visualize the electrical anisotropic conductivity tensor distribution of human calf. It might be helpful to the people who are interested in the imaging of anisotropic characteristics of human body.

Purpose

The purpose of this study is to show the anisotropic electrical property of human calf combining the water-diffusion tensor map from DTI and the apparent conductivity image from MREIT.

Methods

Tuch et al.[1] proposed a method to visualize the anisotropic conductivity tensor map using the DTI technique under the assumption of linear relationship between the effective water diffusion tensor $D_\sigma = S_D \widetilde{D} S_D^T$ and the effective conductivity tensor $\sigma_D = S_D \widetilde{\sigma} S_D^T$:

$$\widetilde{\sigma} = \frac{\sigma_e}{d_e} \widetilde{D} \qquad (1)$$

where S_D is the three orthogonal eigenvectors, $\widetilde{D} = diag(d_1, d_2, d_3)$ and $\widetilde{\sigma} = diag(\sigma_1, \sigma_2, \sigma_3)$ are the diagonal matrices for the diffusion and conductivity tensors, respectively, σ_e is the extracellular conductivity and d_e is the extracellular diffusion coefficient. However, due to the referred extracellular conductivity and diffusivity values, it is still difficult to determine the absolute anisotropic conductivity tensor of human tissues.[2] The MREIT technique can extract the apparent isotropic conductivity and/or current density by measuring B_z which is the one component of magnetic flux density $\mathbf{B} = (B_x, B_y, B_z)$. Using the MREIT reconstruction algorithm, it could be possible to determine the extracellular conductivity and diffusivity ratio (ECDR) by combining the diffusion tensor map. To verify the proposed method, we attached four carbon-hydrogel electrodes (HUREV Co. Ltd, Korea) around the leg of a normal volunteer and injected 5 mA currents through the pair of electrodes. We obtained the diffusion-weighted data using a single-shot spin-echo EPI pulse sequence to measure the diffusion tensor (Fig. 1a) and the magnetic flux densities $B_z^i, i = 1,2$ data by two different injection currents using multi-echo MREIT pulse sequence (Fig. 1b).

Results and Discussion

Figure 2a-c show the MR magnitude images without (a) and with (b and c) diffusion sensitizing gradient, respectively. Figure 2d shows the MR magnitude image by MREIT pulse sequence with a ROI of 7×7 pixels to estimate the anisotropic conductivity values by ECDR factor. Figure 2e and f represent the measured magnetic flux density data by injecting two independent current to reconstruct ECDR factor. Combining the diffusion tensor from DTI and the current density information from MREIT, we calculated the anisotropic conductivity tensor map of human calf. The recovered conductivity tensor and the measured diffusion tensor values at the ROI in figure 2d were as follows;

$$\sigma_D = \begin{pmatrix} 0.3247 & 0.0103 & -0.0052 \\ 0.0103 & 0.2496 & -0.0206 \\ -0.0052 & -0.0206 & 0.2125 \end{pmatrix} \pm \begin{pmatrix} 0.1347 & 0.0214 & 0.0188 \\ 0.0214 & 0.0984 & 0.0236 \\ 0.0188 & 0.0236 & 0.1299 \end{pmatrix} \text{ and } D_\sigma = \begin{pmatrix} 1.7197 & 0.0451 & -0.0297 \\ 0.0451 & 1.3149 & -0.1127 \\ -0.0297 & -0.1127 & 1.1222 \end{pmatrix} \pm \begin{pmatrix} 0.1300 & 0.1061 & 0.0965 \\ 0.1061 & 0.1199 & 0.1043 \\ 0.0965 & 0.1043 & 0.1206 \end{pmatrix}$$

Figure 3a shows the reconstructed ECDR image from the proposed DT-MREIT technique. We recovered the absolute anisotropic conductivity tensor map as shown in figure 3b without any referred extracellular conductivity and diffusivity values.

Conclusion

One of the difficulties in MREIT is to extract the electrical anisotropic conductivity properties of biological tissues from the measured magnetic flux density. Combining DTI and MREIT techniques, we can successfully visualize *in vivo* anisotropic conductivity tensor image of the human calf.

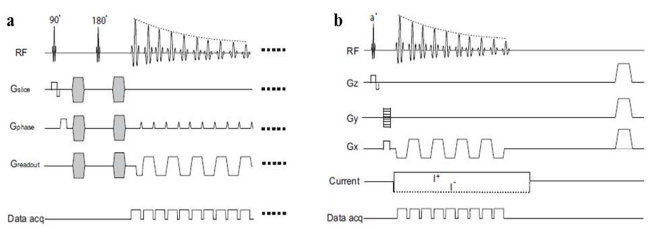

Fig. 1. MR pulse sequences to measure the diffusion tensor from DTI (a) and the magnetic flux density from MREIT (b).

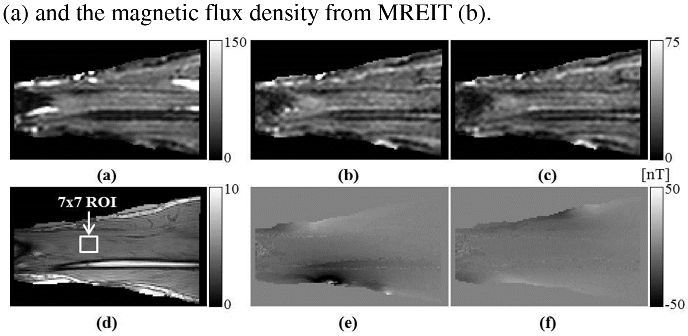

Fig. 2. MR magnitude image from DTI without (a) and with (b and c) diffusion sensitizing gradient. MR magnitude image (a) from MREIT with a 7×7 ROI to measure the conductivity tensor values and measured $B_z^i, i = 1,2$ data (b and c).

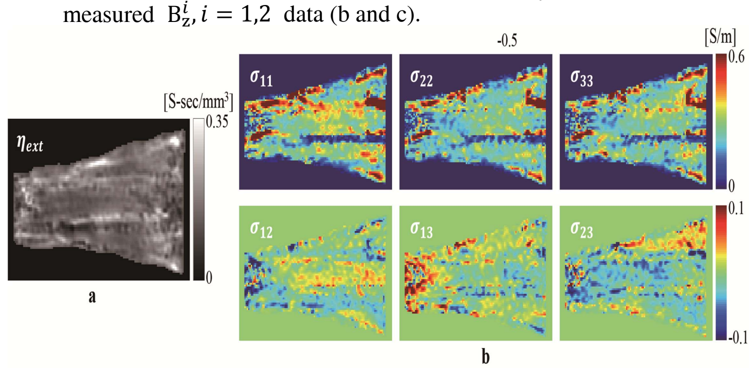

Fig. 3. (a) Reconstructed ECDR from both the DTI and MREIT imaging experiment. (b) Components of reconstructed conductivity tensor of the human calf.

References

1. Tuch DS, Wedeen VJ, et al. Conductivity tensor mapping of the human brain using diffusion tensor MRI. Proc. Nat. Acad. Sci. 2001;98:11697-11701.
2. Kim HJ, Kim YT, et al. In vivo high-resolution conductivity imaging of the human leg using MREIT: The first human experiment. IEEE Trans. Med. Imaging 2009;28:1681-1687.