Electrical conductivity estimation from diffusion tensor and T2: a silk yarn phantom study

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Introduction

Information about electrical conductivity distribution inside biological tissues is useful for many biomedical studies. Especially, conductivity mapping of a human brain would play great roles to enhance accuracy of EEG or MEG source localization for brain function studies. Even though EIT (Electrical Impedance Tomography) could provide conductivity images of the human body, EIT seems not practical for human brain imaging due to its poor sensitivity and low spatial resolution. Tuch et al. introduced a theory that the low frequency electrical conductivity tensor of biological tissues has strong correlation with the diffusion tensor of water molecules inside the tissues [1]. Pelal et al. reported that there is strong correlation between the water molecule diffusion coefficient and the transverse relaxation time constant in frog sciatic nerve tissues and the correlation comes from the compartmental structure of the neuronal tissues [2]. In this study, we have experimentally shown the cross-property relation among electrical conductivity, diffusion, and T_2, using a silk yarn phantom.

Methods

To experimentally verify the cross-property relation, we constructed a phantom using silk yarn and electrolyte solution as shown in figure 1(a). The silk yarn is well known to have high water permeability. We placed the silk yarn along the z-direction. We filled the phantom with electrolyte solution consisting of NaCl (3.125g/l) and distilled water. The electrolyte space in the phantom mimics the extracellular space in biological tissues while the silk yarn mimics the intracellular space. The conductivity of the electrolyte was controlled to be 0.625 S/m. After measuring the diffusion coefficient and T_2 in perpendicular or parallel direction with respect to the silk bundle direction, we measured the electrical conductivity of the silk yarn phantom using an impedance analyzer at the frequency of 1 KHz. For the conductivity measurements, we placed the gold-coated copper plates as shown in figure 1(b). With the electrode plate configuration, we measured the electrical conductivities in parallel (σ) or perpendicular ($\sigma_\perp$) directions with respect to the silk bundle direction. For the mapping of two orthogonal diffusion coefficients (D, $D_\perp$), we performed spin echo imaging with TR=1000ms and TE=70ms using a 3.0 Tesla MRI system. The time period of diffusion gradient was 35ms and the *b*-value was 600sec/mm^2. For the T_2 measurement, we performed spin echo T_2 imaging with TR=1000ms and TE$_1$=11ms, TE$_2$=27 ms. We first measured the T_2 values ($T_{2,}$) with the silk yarn aligned in parallel to the main magnetic field direction, and then we rotated the phantom 90 degree in the zx-plane for the measurement of the other T_2 values ($T_{2,\perp}$) as shown in figure 1(b).

Results

Table 1 shows the cross-property relation among the electrical conductivity, diffusion, and T_2 values of the silk yarn phantom. As expected, all the three physical constants have higher values when the measurement direction was set to the parallel direction with respect to the silk bundle. This implies that electrical conduction and diffusion motion are more active in the parallel direction and the higher diffusion motion makes the longer T_2 value in the parallel direction. The ratios between the perpendicular and parallel values are 1:1.24 in electrical conductivity, 1:1.24 in diffusion, and 1:1.26 in T_2.

Discussions and Conclusions

The three ratios of the electrical conductivity, diffusion, and T_2 are very similar indicating that all the three physical constants are strongly dependent on the compartmental structure of biological tissues and they are strongly correlated among them. We think that electrical conductivity of biological tissues can be estimated from their diffusion and T_2 values. We plan to measure the three physical constants of various kinds of biological tissues to develop a conductivity estimation model based on the diffusion and T_2 values measured with MRI.

References

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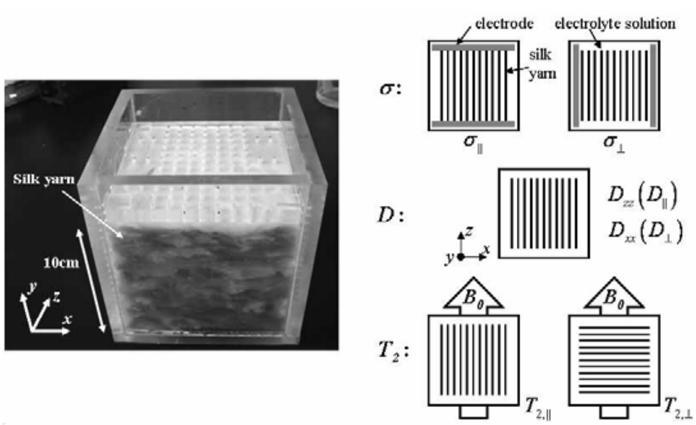

(a) (b)

Fig. 1 (a) The silk yarn phantom. (b) top: electrode configuration for conductivity measurements, middle: diffusion coefficient measurements, bottom: T_2 measurements.

Table 1. Measured electrical conductivity, diffusion, T_2 values.

	Conductivity (S/m)		Diffusion (mm/s^2)		T_2 (ms)	
Component	$\sigma_\perp$	σ	$D_\perp$	D	$T_{2,\perp}$	$T_{2,}$
Measured value	0.41	0.51	2.17	2.70	62	78
Ratio (⊥:)	1:1.24		1:1.24		1:1.26	