Observation of regional variations of conductivity in in-vivo human brain

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***Target audience*:** Researchers with interests in in-vivo electrical property mapping.

***Purpose*:** Electrical conductivity of human brain reveals physiological properties related to ion concentration, bound water (> 100MHz) and temperature [1,2]. Due to the relationships between electrical conductivity value and these physiological factors, electrical conductivity has the potential to be a powerful bio-marker. Recently, magnetic resonance electrical property tomography (MREPT) has been developed for clinical applications (systematic brain tumor) [3] and biological characterization (ion concentration and pH) [4,5] However, due to the lack of SNR and systemic error on tissue boundaries, there are some restrictions to quantify the electrical conductivity to the sub-divisional brain tissue level. In this study, we observe conductivity values of regional brain tissues by using a weighted polynomial fitting technique with an adaptively generated weighting factor [6].

Experiment: In-vivo imaging (3 volunteers) was performed on a 3T clinical scanner (Siemens Tim Trio) with a 12-channel head coil using 3D TrueFISP sequence (α=45°, TR/TE≈4.8/2.4ms with 4 averages) and 3D MPRAGE sequence (α=9°, TR/TE/TI = 2300/3/900ms) for voxel size = 1×1×1 mm^3 (Total scan time≈15min).

Conductivity Reconstruction: Conductivity values (σ) were measured using only transceive phase (φ) that was acquired from TrueFISP sequence as $\sigma = (2\omega\mu_0)^{-1}\nabla^2\varphi$ [7] where ω is Larmor frequency and μ_0 is the magnetic permeability. To measure regional conductivity values, weighted polynomial fitting technique was used to calculate the Laplacian operator. Weighting factors for fitting were adaptively generated using MPRAGE image as a reference. Denote MPRAGE image as I(r) and then the weighting factor at each target voxel r_0 was defined as $w(r,r_0,D)_\Omega = N_{\Omega,D}(|I(r)-I(r_0)|)$ where N is the normal distribution with zero-mean, standard deviation D and Ω is the voxels inside the fitting kernel. After fitting, to stabilize the conductivity image, a bilateral filter was applied. When using multi-Rx, EPT has systematic errors due to inhomogeneous B_1^- magnitude [8]. Therefore, to correct this systematic error, we applied a multi-Rx combine algorithm [8].

Segmentation: To overcome cerebrospinal fluid (CSF) contamination in conductivity image from the filtering process, the CSF were excluded from the mask by thresholding regions where magnitude was larger than 15% of maximum value of TrueFISP magnitude image.

Results: Figure 1 shows conductivity images reconstructed. By using MPRAGE image to restrict fitting for homogeneous tissues, conductivity images could be acquired for regional brain tissues. Table 1 shows that the average conductivity values between sub-regional brain tissues are different. For sub-cortical region, caudate nucleus, putamen and thalamus showed slightly different average conductivity values (0.78, 0.66 and 0.70 S/m). Especially, caudate nucleus showed higher conductivity value than the values of other gray matters. In addition, for white matter, genu and splenium also showed different conductivity values (0.33 and 0.45 S/m).

Figure 1 also shows conductivity images prior to and after CSF exclusion. For the case of conductivity reconstruction that excludes only skull and scalp regions, average conductivity values of caudate nucleus, thalamus and cortical region of gray matter were 1.05, 0.83 and 0.79 S/m that were larger than values of gray matter in literature (0.59 S/m) [1]. After excluding the CSF region, these values decreased to 0.78, 0.70 and 0.64 S/m (Table 1).

Discussion & conclusion: Regional variations of conductivity using high resolution acquisitions were observed in this preliminary study. CSF may hamper in estimating conductivity values of the brain tissues located near CSF. Therefore, to observe conductivity values of soft brain tissues, elimination of CSF prior to reconstruction may be helpful. As previously reported [7], phase-based EPT provides biased conductivity values but the acquired conductivity values were similar to the literature values [1] measured ex-vivo for global white and gray matter. There were differences between conductivity values of each white matter and each gray matter. The microstructural underpinnings to these regional variations should be explainable. Further studies should be performed to confirm the repeatability and to show intra and inter-subject variations.

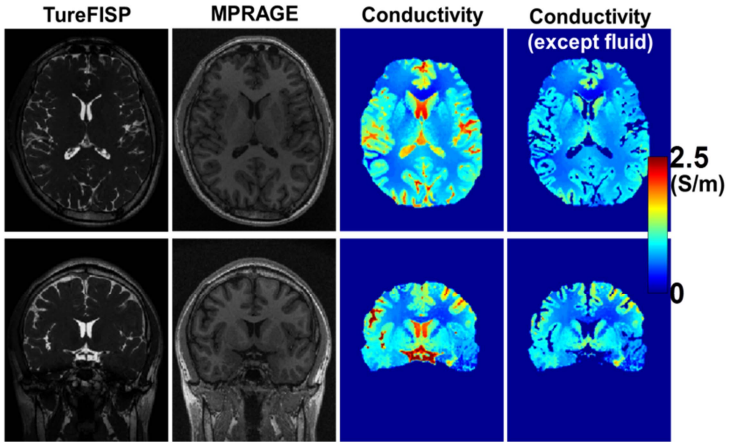

Figure 1. TrueFISP, MPRAGE and conductivity (w/o and w/ CSF exclusion) images

	Volunteer 1	Volunteer 2	Volunteer 3	Average.
Cortical gray matter	0.65 ± 0.12	0.67 ± 0.18	0.67 ± 0.18	0.64 ± 0.03
Caudate nucleus	0.81 ± 0.12	0.88 ± 0.21	0.81 ± 0.21	0.78 ± 0.05
Putamen	0.69 ± 0.05	0.68 ± 0.04	0.68 ± 0.04	0.66 ± 0.04
Thalamus	0.73 ± 0.05	0.71 ± 0.11	0.71 ± 0.11	0.70 ± 0.04
White matter	0.48 ± 0.05	0.49 ± 0.07	0.49 ± 0.07	0.49 ± 0.02
Genu	0.30 ± 0.12	0.33 ± 0.11	0.36 ± 0.12	0.33 ± 0.03
Splenium	0.42 ± 0.05	0.48 ± 0.05	0.48 ± 0.05	0.45 ± 0.03

Table 1. Average conductivity values (± standard deviation) of regional brain tissues. Unit of conductivity is S/m.

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