The dielectric properties of brain tissues: variation in electrical conductivity with tissue sodium concentration and tissue water content at 3T/4T

YuPeng Liao[1], Sandro Romanzetti[1], Vincent Gras[1], DengFeng Huang[1], and N. Jon Shah[1,2]

[1]*Institute of Neuroscience and Medicine-4, Forschungszentrum Juelich, Juelich, Germany,* [2]*JARA-Faculty of Medicine, RWTH Aachen University, Aachen, Germany*

Introduction: Knowledge of tissue dielectric properties is important in many areas, from efficiently coupling of energy into the tissue during hyperthermia therapy to the prediction of local SAR for UHF MRI [1]. On a more basic level, at frequencies >100MHz, tissue dielectrics properties reflect the concentrations of intra- and extra-cellular electrolytes in tissues, and display similar behaviour to saline solution. Previously, report shows the volume fraction of water is highly correlated with tissue conductivity at 0.1GHz [2]. In this study, we computed the proton density (PD), tissue sodium concentration (TSC) and conductivity in healthy volunteers. This combined study of the three maps, for the first time, allows us to test these two hypotheses with the aim that the in vivo and empirical relationship model may be used to predict dielectric properties in other frequency and tissues.

Methods: A phantom containing 9 tubes filled with saline at different concentrations was prepared. The conductivity of each sample was measured with a dielectric probe (DAK-12, SPEAG, Switzerland). PD images and transceiver maps of healthy volunteers were acquired on Siemens 3T (Erlangen, Germany Tim Trio using a 12 channel PA head coil). Sodium images were obtained on a home-assembled Siemens 4T whole body scanner using a dual 1H/23Na birdcage head coil. The tissue conductivity (σ) was estimated based on electrical properties tomography technique [3]: $\sigma = (\Delta\Phi)/\ (2\mu\omega)$ where Δ represents the Laplacian operator, μ the magnetic permeability, and ω the Larmor frequency. The transceiver phase was acquired from a 3D TrueFISP sequence (TR/TE=5.0/2.4ms, resolution: 1.2 mm isotropic). A local quadratic fitting of the transceiver phase was performed before the second-order derivative. PD images were acquired at 3T using a 2D FLASH acquisition (in plane resolution 1mm, TR=1.8, FA=40^{o}) with correction factors for T1, T2* and B1 transmit and receive non-uniformities [4]. The corrected map was normalized to the CSF signal. TSC maps were acquired using a twisted projection imaging (TPI) sequence (3 mm nominal resolution, TR=1900ms, TI=900ms, FA=90^{o}), with flip angle correction. TSC calibration was performed using external reference samples measured simultaneously with in vivo data.

Results: Fig 1a shows the estimated tube conductivity maps and the sodium concentration (with 3 reference tubes for signal calibration). Fig 1b plots the relationship between the sodium concentration and conductivity (both measured with probe and estimated from the transceiver phase). Estimated brain tissue conductivity and TSC in one volunteer are shown in Fig 2a. Regions-of-interests (ROI), including white matter, cerebrospinal fluid (CSF), putamen, and splenium of the corpus callosum, were selected in Fig 2b. TSC levels in the ROIs are plotted against their respective conductivities. Figure 3a shows co-registered brain conductivity and water content, normalized to CSF. The joint histogram of conductivities and proton densities is shown in Figure 3b.

Discussion & Conclusions: Phantom experiments show a good linear relationship between sodium concentrations and conductivity in various saline solutions in the physiological range. In vivo measurements, although limited by SNR and partial volume effects, did not show a clear relationship between conductivity and TSC. The mean values of ROIs still comply with the saline solutions model. The conductivity of brain tissue at 3T increases with the volume fraction of water, which can be explained by the model of proteins suspended in electrolyte made by Bull [5]. Further group study is needed to increase the generalizability of these findings.

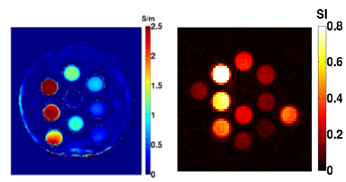

Fig1 (a) Conductivity and Sodium map

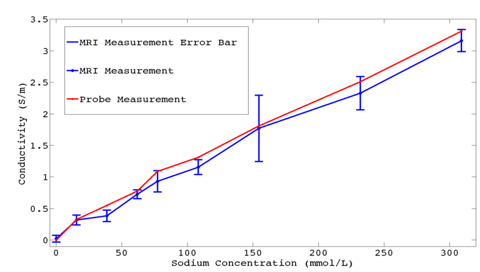

Fig1 (b) Phantom and dielectric probe measurement

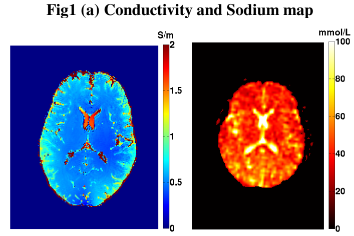

Fig2 (a) In vivo conductivity and TSC

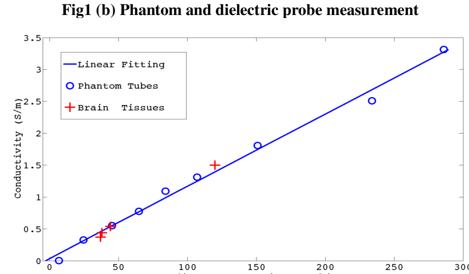

Fig2 (b) In vivo conductivity vs .TSC and Phantom model

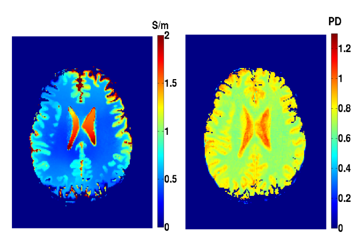

Fig3 (a) In vivo conductivity and PD

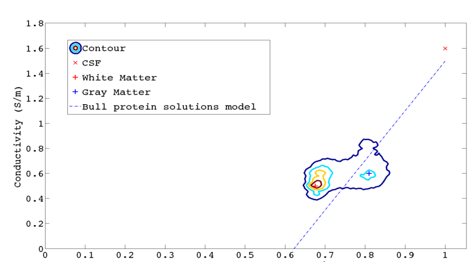

Fig3 (b) In vivo conductivity vs. water content

References:

[1] Esrick et al.(1994) *Phys.Med.Biol*,39:133-44. [2] Foser et al.(1989) *Crit.Rev.BiomedEng*,1:25-104 .[3] Katscher et al.(2009) *IEEE,TMI*,28:1365-74.[4]Abbas et al.(2004) *MRM*,6:1735-45.[5] Bull et al.(1969) *Colloid Interface* 29:492-5