[23]Na-MRI and EPT: Are sodium concentration and electrical conductivity at 298 MHz (7T) related?

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Target audience Basic scientists/(bio)physicists interested in the relation between electrical conductivity and tissue composition.

Purpose MRI offers the possibility to measure the electrical conductivity at the Larmor frequency via a technique termed electrical properties tomography (EPT)[1]. *In vivo* conductivity maps obtained with this technique have confirmed that the conductivity is highly heterogeneous throughout the body. It is assumed that the conductivity at RF frequencies (>100 MHz) is not affected by impaired ion mobility (e.g. by cell membranes), but only by ion concentration and more specifically only by the NaCl concentration[2]. Therefore, the conductivity in tissue and simple saline solutions should behave the same as a function of the sodium concentration. Comparing EPT-based conductivity maps and [23]Na-MR images offers a unique possibility to investigate this hypothesis *in vivo*. The important implication is that EPT may be used as a surrogate for [23]Na-MRI.

Methods A phantom incorporating 6 inner compartments with known NaCl concentrations was constructed (30, 40, 50, 70, 175, 250 mM in 2% agarose). The conductivity was measured with a dielectric probe (85070E, Agilent Technologies, Santa Clara, CA, USA). *In vivo* scans were performed on healthy volunteers. The EPT reconstruction was based on the Helmholtz equation, which requires measurements of the B_1^+ amplitude and phase. Imaging parameters are shown in Table 1. The [23]Na-MRI and conductivity maps were aligned using point-wise registration (Osirix, Osirix Foundation, Geneva, Switzerland). ROIs of several compartments (thalamus, insula, GM, ventricles) were outlined and for each the mean and standard deviation of the conductivity and Na signal intensity (SI) were derived. A graphical analysis of residuals was used to verify that the observed relation between the Na-SI and the conductivity in tissue can fully be explained by a model derived for saline solutions[3].

Table 1: Imaging parameters

	Na (phantom)	Na (in vivo)	B_1^+ amplitude	B_1^+ phase
Sequence	GRE Radial UTE	GRE	GRE (AFI)	SE
TR(/TR_2)	11	14	50/200	1200
TE (ΔTE)	0.44	1.36	2.4	7.1
Res. (mm)	3.5×3.5×7 (eff. 2.75×2.75×3.5)		2.5×2.5×5	
Coil	T/R Quadrature [23]Na birdcage (custom built)		T/R Quadrature birdcage (Nova Medical)	
Scanner	7T (Philips, Cleveland, USA)			

Results Figure 1 plots the measured conductivity (dielectric probe) versus sodium concentration in the saline phantom, showing good agreement with the model predictions published by Stogryn[3] for saline solutions (dotted line). Also plotted are the measured MRI [23]Na signal intensities versus the measured conductivity, which lie close to the model line. An example of an in vivo conductivity image is shown in figure 2. Figure 3(a) shows in vivo results from different areas of the brain for which the Na-SI versus the conductivity is plotted. In Figure 3(b) a graphical analysis of residuals with respect to the model of Stogryn is shown. The [23]Na-SI was normalized using the SI of a small vial (H_2O,100 mM NaCl in 2% agarose) which was placed close to the head. The residual analysis shows a maximum deviation of ~ ±10 mM, with no positive or negative bias in the results.

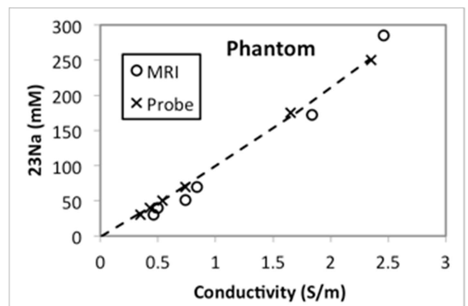

Figure 1: Phantom and dielectric probe measurements

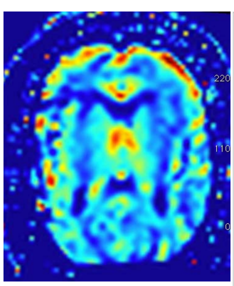

Figure 2: *In vivo* conductivity map (EPT)

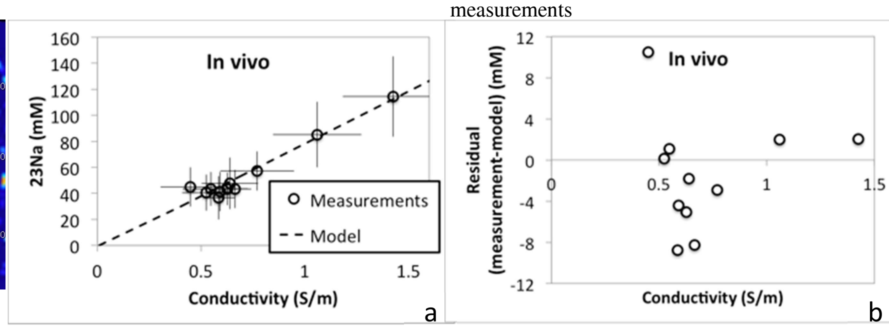

Figure 3: *In vivo* **a)** conductivity vs. [23]Na and model for saline solution **b)** residual analysis of Fig. a.

Discussion: Phantom results show that our setup enables quantitative measurements of the conductivity and sodium concentration in the physiological range. To further verify the applicability of the Stogryn model to predict the tissue sodium concentration based on the electrical conductivity, (tissue) samples at different temperature and with different composition (e.g. neoplastic tissue) should be tested.

Conclusion Based on the graphical analysis of residuals, it is concluded that the conductivity of healthy brain tissue at 298 MHz can be described using a model derived for saline solutions. In other words, the conductivity is directly related to ion concentration, and barriers to ion mobility are not important at this frequency. In tissues where sodium is the dominant electrolyte, this should enable direct extraction of sodium concentrations from electrical conductivity images.

References [1]Katscher et al. (2009) IEEE TMI, 28:1365-74, [2]Pethig, (1984) IEEE TEI, EI-19:453:74, [3]Stogryn, (1971) IEEE TMTT, 19:733-6