Imaging conductivity and local SAR of the human brain

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Introduction: Electric Properties Tomography (EPT) provides a theoretical framework for the determination of electric conductivity and local SAR using a standard MR system [1]. These two parameters could be of high interest in clinical MR and MR hardware engineering. Firstly, local SAR is of major interest in high field MR. Secondly, conductivity could be used as a parameter for diagnosis. For instance, studies report that healthy and malignant tissue reveal conductivity contrast [2]. Other studies report alteration of electric properties in connection with stroke [3] or myocardial infarction [4]. In this study, initial results on *in vivo* brain conductivity imaging and local SAR determination via EPT are shown.

Theory: In the framework of EPT, local SAR and electric conductivity σ are determined by integrating and differentiating a standard B1 map, representing the dominant spatial magnetic field component of a birdcage RF coil [1]. The central EPT equation is derived from a line integral over Amperes law divided by Faradays law:

$$\oint_{\partial A} \vec{\nabla}\times\vec{H}(\vec{r})d\vec{r} \Big/ \mu_0\mu_r\omega^2 \int_A \vec{H}(\vec{r})d\vec{A} = \oint_{\partial A} \varepsilon(\vec{r})\vec{E}(\vec{r})d\vec{r} \Big/ \oint_{\partial A} \vec{E}(\vec{r})d\vec{r} \approx \varepsilon(\vec{r}) \quad \text{with} \quad \varepsilon(\vec{r}) = \varepsilon_0\varepsilon_r(\vec{r}) - i\sigma(\vec{r})/\omega . \qquad (1)$$

The determination of the complex permittivity requires several approximations. First, it is assumed that the longitudinal component Hz is negligible for the birdcage RF coil investigated. Then, Eq. (1) assumes that the variation of complex permittivity along the integration path ∂A is smaller than the variation of the electric field along ∂A. Using the complex permittivity obtained from (1), it is possible to obtain the electric fields from Amperes law: $\vec{\nabla}\times\vec{H}(\vec{r})/i\omega\varepsilon(\vec{r}) = \vec{E}(\vec{r})$. Local power density can then be computed according to: $SAR(\vec{r}) \approx \frac{1}{2}\sigma(\vec{r})\vec{E}(\vec{r})\vec{E}^*(\vec{r})$.

Subjects and Methods: Sagittal images of a healthy volunteer have been obtained using a clinical 1.5T MR scanner (Philips Medical Systems, Best, The Netherlands). An AFI B1 map [5] was acquired using a Rx/Tx body coil with sequence parameters TR2/TR1 = 5, TR1=27ms, nominal flip angle α = 60°, spatial resolution 1.64×1.64×10 mm³ and 19 slices. An optimized spoiling scheme was used [6] in order to reduce artefacts stemming from remaining transverse magnetization. Additionally, a B0 map has been acquired in order to correct for susceptibility effects (ΔTE = 6 ms).

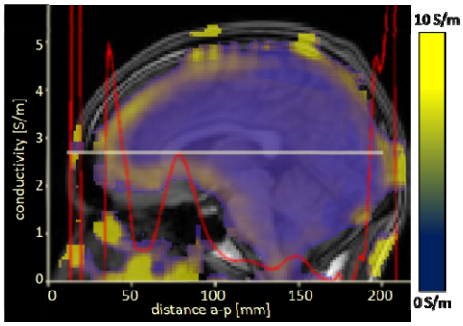
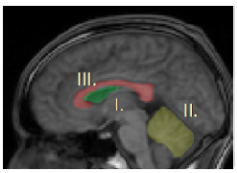


Figure 1: Overlay of conductivity in units of S/m and anatomy. A profile along the indicated line is shown.

Results/Discussion: The reconstructed conductivity is shown in Fig. 1. A quantitative analysis of three regions of interest is given in Fig. 2. The quantitative conductivity (at 64MHz) is found in good agreement with literature values [7,8]. Local SAR (assuming constant mass density) is depicted in Fig. 3. It is found to be relatively high at the boundaries of the brain and in parts of white matter. Being shown in arbitrary units, local SAR could also be computed in absolute values via suitable calibration of the B1 map.



Region of interest	Conductivity	Literature
I. Cerebrospinal fluid	σ = 1.85 ± 0.87 S/m	2.07 S/m [7]
II. Cerebellum	σ = 0.57 ± 0.15 S/m	0.72 S/m [7]
III. Corpus Callosum	σ = 0.24 ± 0.09 S/m	0.21 S/m [8]

Figure 2: Quantitative conductivity in selected regions of interest [S/m].

Conclusion: The EPT framework allows for conductivity and local SAR estimation *in vivo* based on standard B1 mapping. Conductivity forms a new and quantitative contrast for MRI. Local SAR is of tremendous interest in the field of high field MR where SAR issues form a major obstacle. To the best of the authors' knowledge, this is the first time that local SAR has been measured *in vivo*.

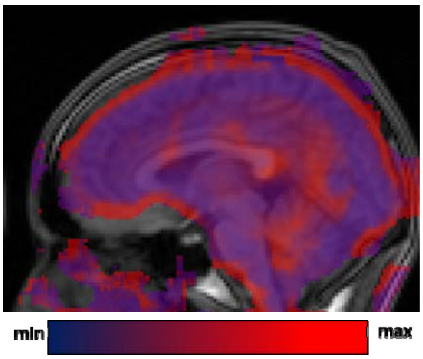


Figure 3: Overlay of local SAR in relative units and anatomy.

References: [1] Katscher U. et al., ISMRM 16 (2008), 1191. [2] Joines W. et al., Med Phys 21 (1994), 547-550. [3] Liu L. Et al., Neurol Res 28 (2006), 31-37. [4] Schaefer M. et al., Bioelectrochemistry 58 (2002), 171-180. [5] Yarnykh VL., MRM 57 (2007), 192-200. [6] Nehrke K., ISMRM 16 (2008) 3144. [7] Gabriel et al., Phys. Med. Biol 41 (1996) 2271–2293. [8] Sekino et al., Neurol. Clin. Neurophysiol. 55 (2004) 1-5.