Permittivity determination via phantom and in vivo B1 mapping

U. Katscher[1], P. Karkowski[1], C. Findeklee[1], and T. Voigt[2]
[1]Philips Research Europe, Hamburg, Germany, [2]Institute of Biomedical Engineering, University of Karlsruhe, Karlsruhe, Germany

Introduction Tissue permittivity might serve as diagnostic parameter, e.g., for oncology [1]. However, the diagnostic use of the permittivity is significantly hampered by the lack of suitable methods to determine the permittivity *in vivo*. A possible approach for the determination of permittivity *in vivo* is given by analyzing the B1 map in the framework of standard MRI, called "Electric Properties Tomography" (EPT) [2]. Hitherto, studies were focussed on the ability of EPT to reconstruct the electric conductivity and local SAR [2]. This study focuses on the EPT reconstruction of the permittivity via numerous phantom and *in vivo* experiments.

Theory Permittivity (together with the electric conductivity) can be estimated from the active magnetic RF field component H^+ via a re-arrangement of the Maxwell equations (see equation) [2]. Here, ε_r denotes the relative permittivity, ε_0 the vacuum permittivity, σ the electric conductivity, and ω the Larmor frequency. The amplitude of H^+ can be determined via standard B1 mapping techniques. The phase of H^+ can be determined, e.g., via the phase of a spin echo image. However, since the permittivity influences predominantly the amplitude of H^+, also reconstructions assuming a constant phase of H^+ were tested. The reconstruction equation is a refinement of the reconstruction discussed in [2], i.e., the reconstruction was performed twice, for a coronal and sagittal reconstruction plane, and the two results were superimposed. The resulting equation does not require any assumption concerning the unknown magnetic field components H_- and H_z. Additionally, compared with the reconstruction suggested in [3,4], it does not require a numerically demanding second derivative of H^+. As in [2-4], the proposed reconstruction yields absolute values of the permittivity.

$$\frac{\oint_{\partial V} \nabla H^+(\mathbf{r}) d\mathbf{r}}{\mu_0 \omega^2 \int_V H^+(\mathbf{r}) d\mathbf{a}} \approx i\sigma(\mathbf{r})/\omega - \varepsilon_0 \varepsilon_r(\mathbf{r})$$

Methods Distilled water was mixed with 2-propanol in 8 different concentrations to obtain ε_r between 35 and 80 (from 25% to 100% water). Additionally, different physiologic conductivities σ = 0.0/0.5/0.8/2.0 S/m were achieved by adding respective amounts of NaCl. However, due to the limited salt solubility in propanol, not all combinations of σ and ε_r could be realized. Bottles with a volume of 200 ml were filled with the fluids, and 2.5 ml Magnevist (Bayer Schering Pharma AG, Berlin, Germany) per liter of phantom fluid was added to enhance the MR signal. Finally, the resulting ε_r were checked by a dedicated sensor [5] and the resulting σ by a commercial conductivity-meter (HI8733, Hanna Instruments, USA). Experiments were performed on a Philips Achieva 1.5T system (Philips Health Care, Best, The Netherlands) using a transmit/receive quadrature head coil. To determine the amplitude of H^+, "Multiple TR B1 Mapping" (MTM) [6] was used, based on 3 repetitions of the "Actual Flip angle Imaging" (AFI) sequence [7] with different TR pairs (TR_{11}/TR_{21}=30/185 ms, TR_{12}/TR_{22}=30/200 ms, TR_{13}/TR_{23}=30/320 ms). Further sequence parameters were α = 60°, voxel size = 1.5×1.5×4 mm³, TE = 1.3 ms. The phase of H^+ was estimated as suggested in [2] via a separate turbo-spin-echo sequence (TE/TR = 25/750 ms, α = 90°, turbo factor = 8, same geometry as for the B1 mapping). Reconstruction was performed using the equation given above. Finally, the described sequences were applied to the head of a volunteer, and the permittivity was reconstructed with and without phase information.

Results Reconstructed and expected phantom permittivities agree well for all investigated conductivities (Fig. 1a). Results of the volunteer study are shown in Fig. 2. The average ε_r in white/gray matter and Cerebro-Spinal Fluid (CSF) agree with literature values (Tab. 1).

Discussion / Conclusion This study underlines the ability of EPT to determine the permittivity in phantoms and *in vivo*, which might become a new parameter for clinical diagnosis. To the best of the authors' knowledge, it is the first time that permittivity has been measured with standard MR. The achievable spatial resolution is of the order of the acquired B1 maps, reduced by blurring arising from the applied calculus operations. Total EPT scan time can be reduced by skipping the phase determination due to its negligible impact on the reconstructed permittivity, at least for the electric properties of human tissue. The occurring noise seems to be higher than for the reconstructed conductivity [2]. This feature, which might arise from $\varepsilon_0\varepsilon_r << \sigma/\omega$ for human tissue at Larmor frequency, shall be investigated in a future study.

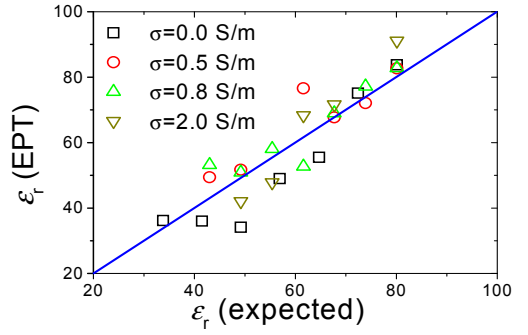

Fig. 1: Permittivity from phantom experiments

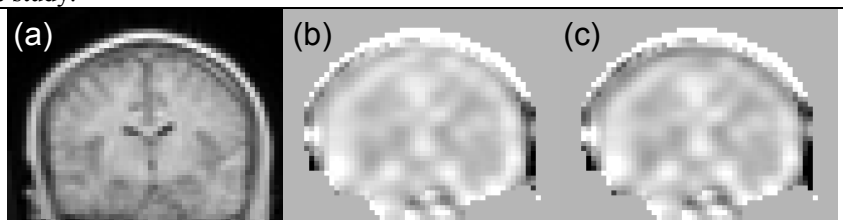

Fig. 2: (a) Anatomy, (b/c) permittivity with / without B1 phase map *in vivo*

Tab. 1	EPT (with B1 phase)	EPT (no B1 phase)	literature [1]
white matter	72±64	63±66	67.8
gray matter	103±69	91±70	97.4
CSF	104±21	98±20	97.3

References: [1] Joines WT et al., Med Phys 21 (1994) 547 [2] Katscher U et al., IEEE Trans Med Imag 28 (2009) 1365 [3] Bulumulla SB et al., ISMRM 17 (2009) 3043 [4] Cloos MA et al., ISMRM 17 (2009) 3037 [5] Findeklee C et al., ISMRM 17 (2009) 2939 [6] Voigt T et al., ISMRM 17 (2009) 4543 [7] Yarnykh VL, Magn Reson Med 57 (2007) 192