Comparing Electric Properties Tomography at 1.5, 3 and 7 T.

A. L. van Lier[1], T. Voigt[2], U. Katscher[2], and C. A. van den Berg[1]
[1]Radiotherapy, UMC Utrecht, Utrecht, Netherlands, [2]Philips Research Europe, Hamburg, Germany

Introduction: Recently, the principle feasibility of Electrical Properties Tomography (EPT) has been shown at different field strengths, 1.5 T [1], 3 T [1b], and 7 T [2]. Using the Helmholtz equation to investigate the effect of the local electrical properties on the B_1^+ field (Eq.1 see also [2]) one can obverse that the effect of the local dielectric properties on the B_1^+ field scales with the (square of the) used angular frequency ω. Therefore, it is expected that at higher field strengths the precision of EPT increases. Furthermore, measurements at higher field benefit from the increased intrinsic SNR. On the other hand, the increased field strength leads to a larger difference between the phase φ^+ of the quadrature transmit (B_1^+) and the phase φ^- of the quadrature receive field (B_1^-), which complicates the derivation of φ^+ from the measurable transceiver phase $\varphi_m = \varphi^+ + \varphi^-$ resulting in systematic errors. Generally, $\varphi_m = 2\varphi^+$ is assumed [1,2]. However, it can be shown that this is only true under low field conditions and that the validity will deteriorate with increasing field strength [1,2]. To determine the optimal field strength for EPT, a systematic study was performed comparing phantom measurements and simulations at 1.5, 3, and 7T.

$$\frac{\nabla^2 B_1^+}{B_1^+} = -k^2 \text{ where } k^2 = \mu\varepsilon\omega^2 + i\mu\sigma\omega \qquad (1)$$

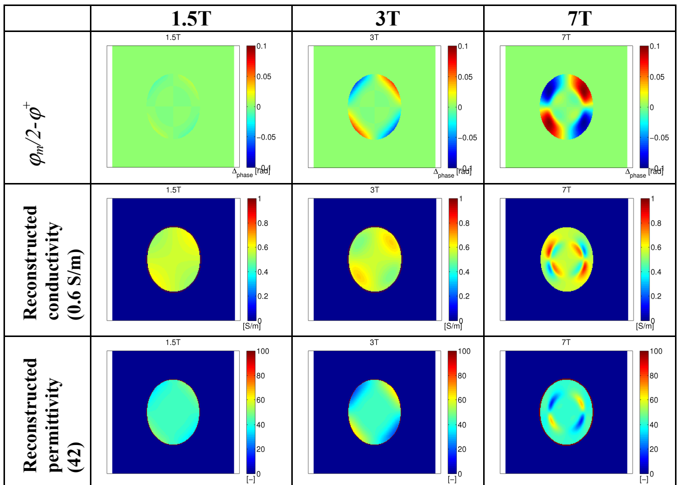

Figure 1: Reconstructions based on simulation results. *Upper row:* $\varphi_m/2 - \varphi^+$ *Centre and bottom row:* Reconstructed electrical conductivity and rel. permittivity resp. based on $|B_1^+|\exp(i\ \varphi_m/2)$.

Methods: The phantom consisted of an elliptical cylinder (d_{major} = 19 cm, d_{minor} = 16 cm), in which a circular cylinder (d = 5.4 cm) was placed off-axis. The ellipse contained H_2O with 3.3g/L NaCl; the cylinder was filled with a mixture of 66 % H_2O and 33 % 2-propanol and 5g/L NaCl. The dielectric properties were measured at the relevant frequencies (64, 128, 300 MHz) using an impedance probe (85070E, Agilent Technologies, Santa Clara, CA, USA). MR scans were performed at 1.5, 3, and 7 T (all scanners: Philips Healthcare) using quadrature T/R head coils. The complex B_1^+ field was determined using a separate measurement of B_1^+ amplitude and phase. The B_1^+ amplitude was measured using the AFI method [3] at 3 and 7T (3D, nom. flip angle = 65° TR1 = 50 ms, TR2 = 340 ms), at 1.5T the double-angle method was used (nom. flip angle 60/120°) [4]. B_1^+ phase was measured using a SE experiment (nom. flip angle: 90°, TR = 1200 ms) at all field strengths [5]. All images were acquired at 2.5×2.5×5 mm resolution; the total imaging time was approximately 15 minutes. Reconstruction of the dielectric properties was based on the framework described by [1]. The resulting conductivity and permittivity maps were compared based on accuracy and precision. Accuracy was defined as mean deviation between the MRI measurement and the impedance probe measurement. Precision was defined as the standard deviation of the MRI-measured electrical properties over 'cylinder' or 'ellipse' area. The areas were defined manually, disregarding the areas close to the compartment boundaries. To investigate the validity of the assumption $\varphi_m = 2\varphi^+$ for the respective field strength, φ_m and φ^+ were calculated for an elliptical cylinder with approximately the average dielectric properties of the head (d_{major} = 19 cm, d_{minor} = 16 cm, σ = 0.6 S/m, ε_r = 42). For the simulations the Bessel Boundary Matching method [6] was used. The simulations were performed for all field strengths assuming a 16 rods birdcage head coil driven in quadrature for transmission and reception.

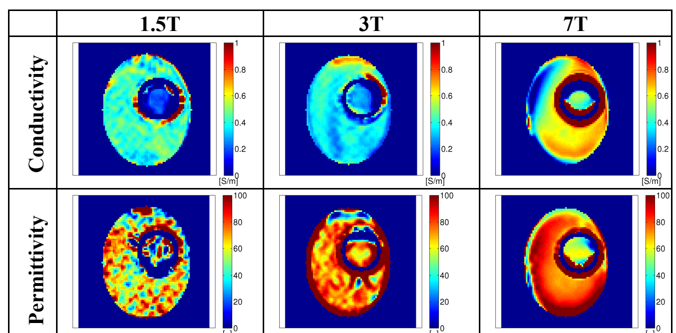

Figure 2: Reconstructions based on measurements of $|B_1^+|$ and φ_m at different field strengths.

Results and discussion: Fig. 1 shows the simulated effect of increasing field strength (i.e. frequency) on the error induced by the assumption: $\varphi_m = 2\varphi^+$. Furthermore, reconstructions of the dielectric properties based on $|B_1^+|\exp(i\ \varphi_m/2)$) instead of the correct complex B_1^+ are shown. The phase assumption becomes less accurate at higher field strengths, which leads to local errors in the reconstruction. In Fig. 2, the measured conductivity and permittivity maps are shown. A distinct difference between the conductivity in the ellipse and cylinder are observed at all three field strengths. At 1.5 and 3T, the maps show fairly homogeneous conductivity distributions, however, with lower SNR at 1.5T. At 7T, a spatial dependence of the reconstructed conductivity is observed. An apparent permittivity contrast is observed only at 3T and 7T, and is lost in noise at 1.5 T. In Fig. 3, a quantitative overview of the EPT maps is given, by comparing the mean and standard deviation of the reconstructed dielectric properties at the three field strengths. Furthermore, the results of the dielectric properties obtained with the impedance probe are shown in this figure. Regarding the conductivity the 7T measurement is most accurate, but less precise than the 1.5T and 3T measurement; the standard deviation in the ellipse at 7T is more than 2 times higher than for the 1.5T and 3T experiment. This can possibly be explained by increased phase error (see Fig. 1). The permittivity mapping at 1.5T and also 3T suffers from low SNR. The 7T permittivity measurement is most precise and accurate, although some spatial dependent fluctuations of the permittivity are observed. The increasing precision of the permittivity can be understood from the quadratic effect of the frequency on the $|B_1^+|$ variations seen in Eq. (1).

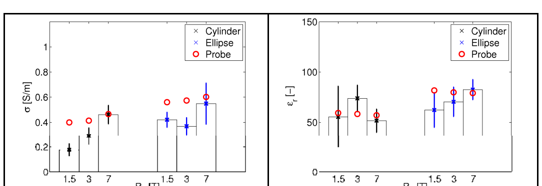

Figure 3: Overview of the dielectric properties measured with EPT experiments and an impedance probe. For the EPT experiment the average and standard deviation are given

Conclusion: Theoretically, 1.5T would be the ideal field strength for EPT as the underlying phase error is minimal. However, the low SNR at this field strength hampers reconstruction on data measured within reasonable measurement times (~ 15 minutes). It is found that for conductivity mapping, 3T is optimal for precision, i.e. it seems to balance the error due to the phase and the needed SNR. On average 7T is most accurate for conductivity mapping. For permittivity mapping, 7T is most optimal as reconstructed permittivity maps at lower field strengths suffer from a (significant) lack of SNR. In future, measurements on a phantom with the approximate dielectric properties of the human head will be performed.

[1] Katscher *et al.,* IEEE Trans Med Imag 28:1365-75, *2009*, [1b] Katscher *et al.,* Proc. ISMRM, p. 4512, *2009* [2] Van Lier *et al.,* Proc. ISMRM p.2864, *2010,* [3] Yarnykh, MRM 57:192-200, *2007* [4] Stollberger and Walch, MRM 35:246-251, *1996,* [5] Voigt *et al*., Proc. ISMRM, p. 2865, *2010* [6] van den Bergen, *et al.,* Phys. Med. Biol. 54:1253–1264, *2009*