

# Determining the patient-specific conductivity of pelvic tumours for use in Hyperthermia Treatment Planning

E. Balidemaj<sup>1</sup>, A.L van Lier<sup>2</sup>, J. Crezee<sup>1</sup>, R.F. Remis<sup>3</sup>, A.J. Nederveen<sup>4</sup>, L.J.A. Stalpers<sup>1</sup>, and C.A.T. van den Berg<sup>2</sup>

<sup>1</sup>Radiotherapy, Academic Medical Center, Amsterdam, Netherlands, <sup>2</sup>Radiotherapy, UMC Utrecht, Utrecht, Netherlands, <sup>3</sup>Faculty of Electrical Engineering, TU Delft, Delft, Netherlands, <sup>4</sup>Radiology, Academic Medical Center, Amsterdam, Netherlands

**Introduction & Theory:** In RF deep hyperthermia pelvic tumors (e.g. cervix or bladder) are heated by application of radiofrequency fields in the 70 to 150 MHz frequency range. To obtain a focussed heating and determine the tumor's SAR absorption, EM modelling is employed which is known as Hyperthermia Treatment Planning (HTP)[1]. An essential step in HTP is the assignment of tumor electrical conductivity as this is the main determining factor in the RF energy absorption of the tumor. Currently, a fixed tumor conductivity is assumed for all patients and tumor sites, however, most tumors have elevated conductivities varying significantly among patients [2,3]. In this study we investigate the feasibility of using Electric Properties Tomography (EPT)[4] to perform assessment of the electrical conductivity of pelvic tumors to improve SAR dosimetry. In a previous study we showed the validity of the crucial  $B_1^+$  phase ( $\phi^+$ ) assumption, i.e.  $2\phi^+ = \phi_m$  ( $\phi_m$ : measurable transceive phase), in a large central region in the human pelvis at 3T [3,5]. Here, we present EPT based conductivity measurements for a pelvic tumor model over a wide range of tumor conductivity and tumor locations. Furthermore, we present *in vivo* conductivity measurements of the human pelvis for a female volunteer.

**Materials & Methods:** For all measurements a pelvic-sized phantom was used, consisting of an elliptical cylinder ( $d_{\text{major}}=34$  cm,  $d_{\text{minor}}=25$  cm, length=40 cm), with a spherical ( $d=10$  cm) compartment mimicking a cervical tumor (Fig. 1). The spherical compartment can be positioned on- or off-axis. The elliptical cylinder contained ethylene glycol (64g/L NaCl) with dielectric properties that matched the volumetric average of the pelvis at 128 MHz ( $\sigma=0.44$  S/m and  $\epsilon_r=30$ , [7]). To cover the whole range of possible  $\sigma$ -values occurring in biological tissue the conductivity of the spherical compartment was varied from  $\sigma = 0.04$  S/m to  $\sigma = 2,00$  S/m in 10 steps by adding NaCl. To test the applicability of the phase assumption for an asymmetric position of the sphere geometry, the spherical compartment was positioned off-center. The dielectric properties were independently verified with an impedance probe (85070E, Agilent Technologies). Furthermore, simulations of the human pelvis (Ella, IT'IS Foundation) and MRI-measurements of the female human pelvis were performed. All experiments were conducted on a 3.0T scanner (Philips Healthcare, Best, The Netherlands) using a 16 channel receive coil. The  $B_1^+$  amplitude map was acquired using the AFI method [8] (3D, nom. flip angle = 65° TR1 = 50 ms, TR2 = 290 ms, 2.5x2.5x5mm<sup>3</sup>, 12 slices). The transceive phase was acquired by a SE experiment (2.5x2.5x5mm, CLEAR, TR = 1200 ms) [9,10] using an uniformity correction method [CLEAR] to compensate for the complex receive sensitivity pattern of the receive coil. Conductivity values were reconstructed using a Helmholtz based reconstruction [3].

**Results & Discussion:** In Fig. 2 we present the reconstructed  $\sigma$ -maps of only 3 phantom measurements with increasing  $\sigma$ -value in the spherical compartment. The reconstructed average  $\sigma$ -values of the spherical compartment are in very good quantitative agreement with the probe measurements, as is illustrated in figure 3. Figure 4 shows the reconstructed  $\sigma$ -map with the spherical compartment ( $\sigma=0.64$  S/m, probe measurement) positioned on-axis (Fig. 4a) and off-axis (Fig. 4b). The histograms (Fig.4c,d) illustrate the capability of EPT to reconstruct  $\sigma$ -maps of tumors located off-axis. We note that the  $\sigma$ -values of the off-axis located compartment have a skewed normal distribution (Fig4d) while the data of the on-axis location are normally distributed (Fig.4c). This effect arises from the impact of the asymmetry on the  $B_1^+$  phase approximation. However, the effect is marginal and will not corrupt tumor conductivity measurement significantly. Using *in vivo* measurements of the  $\phi_m$  (Fig.5e) and  $|B_1^+|$  (fig.5f) we are able to reconstruct a  $\sigma$ -map (Fig.5c) which correlates with water/fat contrast of a Dixon scan (Fig.5d). Water like tissue are assigned higher conductivity than fat tissue. Due to the large heterogeneity of the pelvis anatomy and the assumption of piecewise continuous dielectric properties in the reconstruction, the quality of reconstructed  $\sigma$ -maps are corrupted at abrupt tissue boundaries. This effect is also confirmed by the EPT reconstruction based on the simulations (Fig. 5b). This effect will need to be addressed before EPT can be used to reconstruct complete dielectric model of the whole pelvic region.

**Conclusions:** The phantom measurements demonstrated the ability of EPT to measure quantitatively the  $\sigma$ -value of pelvic tumours. We have shown a good correlation between the reconstructed  $\sigma$ -values and probe measurements for a wide range of  $\sigma$ -values and for off-axis located spherical compartment. As most pelvic tumours are located in the central region of the pelvis these results are promising for HTP. *In vivo* measurement illustrated the applicability of EPT in pelvic region, however, the reconstruction of  $\sigma$ -map of the whole pelvic region requires further investigation.

**References:** [1] De Greef, PMB 56(11):3233-3250 (2011). [2] Joines, Med Phys. 1994; 21: 547-50. [3] Van Lier, MRM 2011. [4] Katscher, IEEE 28:1365-75, 2009. [5] Balidemaj, ISMRM, 3468, 2012. [6] Van Lier, ISMRM p.4464, 2011. [7] Gabriel, Phys. Med. Biol. 41 (1996), 2251-2269. [8] Yarnykh, MRM 57:192-200, 2007. [9] Voigt, ISMRM, p. 2865, 2010. [10] Van Lier, ISMRM p.125, 2011.

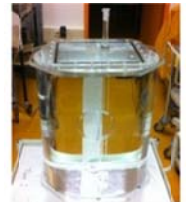


Figure 1. Pelvic-sized phantom.

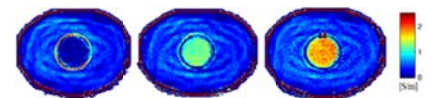


Figure 2. Phantom results,  $\sigma = 0.01, 1.18, 1.74$  (probe measurements), respectively.

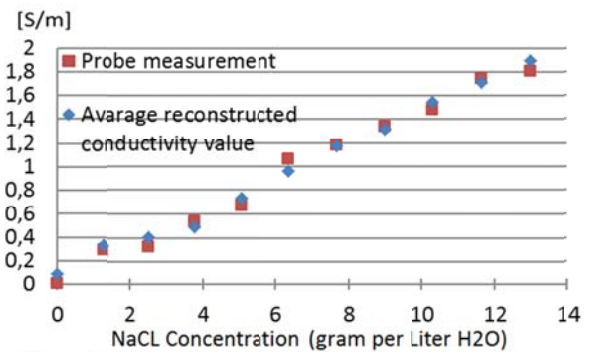


Figure 3. Conductivity based on probe measurements and EPT in spherical compartment.

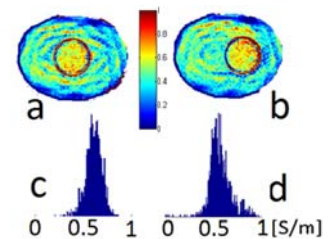


Figure 4. On-axis and off-axis located inner compartment.

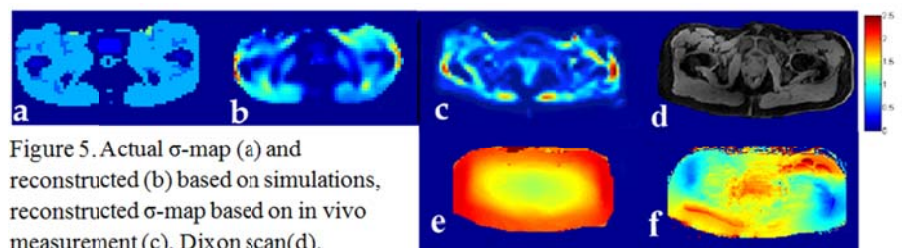


Figure 5. Actual  $\sigma$ -map (a) and reconstructed (b) based on simulations, reconstructed  $\sigma$ -map based on *in vivo* measurement (c), Dixon scan (d), measured  $\phi_m$  (e) and  $|B_1^+|$  (f).