In vivo reconstructed conductivity values of cervical cancer patients based on EPT at 3T MRI

Edmond Balidemaj[1], Peter de Boer[1], Hans Crezee[1], Rob Remis[2], Lukas Stalpers[1], Aart Nederveen[3], and Cornelis A.T. van den Berg[4]
[1]*Radiotherapy, Academic Medical Center, Amsterdam, Netherlands,* [2]*Circuits and Systems Group, TU Delft, Delft, Netherlands,* [3]*Radiology, Academic Medical Center, Amsterdam, Netherlands,* [4]*Radiotherapy, UMC Utrecht, Utrecht, Netherlands*

Target audience: scientists working on SAR assessment and electric properties tomography

Introduction: Electric tissue properties (conductivity σ and permittivity ε_r) are essential for SAR assessment at high field MRI and other applications such as Hyperthermia Treatment Planning. An estimated whole-body SAR is normally provided during the scan, but local SAR cannot be monitored due to lack of patient-specific electric properties. To determine local SAR deposition, numerical simulations are therefore usually performed using generic body models [1]. The electric properties that are assigned to the various tissue types are generally based on the well-known Gabriel data [2]. Most of these properties have been measured ex-vivo using animal tissues. A few studies comparing in vivo and ex vivo conductivity of human tissue (e.g. liver tissue in [3]) and various animal studies (e.g. [4,5]) have shown that most tissue types have elevated conductivity values when measured in vivo. In vivo patient-specific electric properties are therefore required for more accurate SAR assessment. In this study we have performed in vivo conductivity reconstruction of muscle, bladder and tumor of 13 cancer patients.

Materials & Methods: The electric tissue conductivity values were reconstructed by Electric Properties Tomography (EPT) [6] from measured B_1^+ data. All experiments were conducted on a 3.0T scanner (Ingenia, Philips Healthcare, Best, The Netherlands) using a 16 channel receive coil. The B_1^+ amplitude map was acquired using the AFI method [7] (3D, nom. flip angle = 65° TR1 = 50 ms, TR2 = 290 ms, 16 slices). The transceive phase was acquired by an SE experiment (TR = 1200 ms, CLEAR) [6,8,9]. Conductivity values were reconstructed using a Helmholtz based reconstruction [8,9]. In vivo MR measurements of 13 cancer patients were conducted. One patient was diagnosed with uterine cancer (adenocarcinoma) and 12 patients were diagnosed with cervical cancer (Squamous-cell carcinoma). Due to scan time limitations, a more coarse resolution of 5mm isotopic was used on most of the patients. Peristaltic motion was reduced with the intravenous injection of *Buscopan*®. Patient scans for this study were performed in accordance with the approval of the Medical Ethics Board. Gross tumor volume (GTV) was delineated by a radiation oncologist based on mutually registered CT and T2-weighted MRI images. Mean ± standard deviation of muscle, bladder and tumor were based on manual segmentation of these tissue types based on T2-weighted images. Care was taken not to include regions where boundary artefacts were observed. As the kernel used in EPT requires many pixels of a particular tissue type, not all the patients had a tumor and bladder size that was large enough to be reliably reconstructed using EPT.

Results & Discussion: In figures 1a and 1b the T1w image and the reconstructed conductivity map of one of the patients are depicted, respectively. In fig. 1c the reconstructed muscle conductivity values (blue) of all patients are depicted and compared to the literature value (0.72S/m – light blue bar) from [2]. Elevated σ values for most patients are observed with 15-30% higher values compared to the literature value. To the best of our knowledge, there is no data available of in vivo human muscle. Reported values of in vivo σ of feline skeletal muscle at 100MHz are 0.95-0.99S/m [4] and 0.90S/m [5]. Conductivity values at 128MHz are not reported in [4,5], however, since the conductivity of muscle increases with frequency, we expect that the in vivo conductivity at 128MHz is slightly higher than the aforementioned values. In figure 1d the reconstructed conductivity of bladder/urine (purple) of 7 patients is depicted. In the same figure the bladder conductivity (light purple) is shown as used in numerical human models [1,2]. The σ of bladder reported in the literature corresponds to bladder wall tissue and does not account for highly conductive urine. It is observed that the reconstructed bladder conductivity is up to 10 times higher compared to the conductivity value used in numerical models. However, the urine conductivity reported in this work is in good agreement with the conductivity values reported in a recent study of porcine urine samples [10]. Furthermore, a relatively large conductivity spread between urine samples was also observed in [10]. In figure 1e, the conductivity values of the Squamous-cell carcinoma and adenocarcinoma are depicted. The conductivity of cervical tissue as reported in [2] is depicted in Fig. 1e (light red bar). No further information is available on conductivity values of cervical tumors at 128MHz. It is observed that in most patients the σ of the tumor is 5-12% higher than muscle σ. The reconstructed σ of the adenocarcinoma tumor is 22% higher than muscle conductivity.

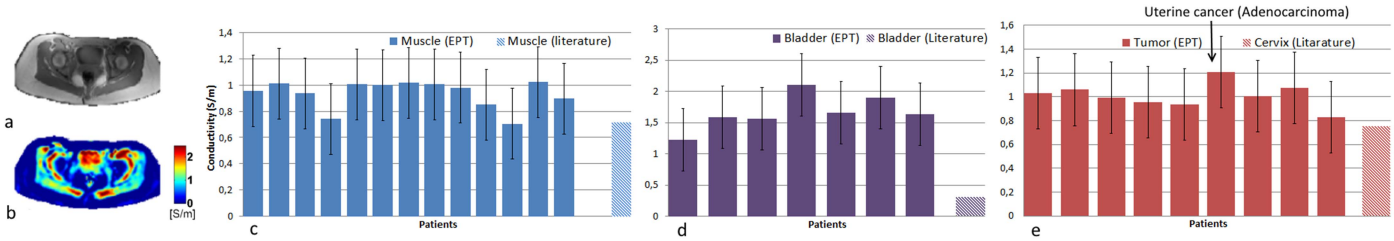

Fig 1. T1w MRI image (a) and the reconstructed conductivity map (b) of a patient. Reconstructed and literature conductivity values of muscle (c), bladder (d) and cervical tumor tissue (e).

Conclusions: We have presented first human in vivo conductivity data of muscle, bladder and cervical tumors at 3T based on EPT. Our findings regarding muscle are confirmed by scarcely available in vivo data of feline muscle tissue. The reconstructed bladder/urine conductivity values are in good agreement with the measurements of porcine urine reported in recent literature, however, the reconstructed values are much higher than the values used in numerical models. In addition, we have observed that the commonly unknown tumor conductivity is 5-12% higher compared to muscle conductivity. These results demonstrate the importance of accounting for conductivity values in living conditions when incorporating electric properties data into numerical models. Future work will, therefore, focus on the effect of these findings on SAR deposition in MR and Hyperthermia.

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References: [1] Christ et al., PMB. 55:N23-N38, 2010. [2] Gabriel et.al., PMB 41:2251-2269, 1996. [3] O'Rourke et.al., PMB 52:4707-4719, 2007. [4] Stuchly et.al., Biolectromagnetics 2:93-103, 1981. [5] Surowiec et.al., PMB 31:901-909, 1986. [6] Katscher et.al., IEEE 28:1365-75, 2009. [7] Yarnykh, et.al., MRM 57:192-200, 2007. [8] Van Lier et.al., MRM 71(1):354-63, 2013. [9] Balidemaj et.al., MRM 2014. [10] Peyman, et.al., PMB 57:N339-344, 2012.