In vivo B1-based SAR determination in a multi-transmit system with DREAM

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Introduction: A central issue of parallel RF transmission is the SAR management to ensure patient safety [1,2]. The additional degrees of freedom available in parallel transmission hamper straight-forward SAR estimations as applied for single channel transmission. As an alternative to the usually applied model-based SAR estimation (see, e.g., [3,4]), a new method has been proposed to estimate SAR from the acquired B1 maps [5]. This B1-based SAR determination has been successfully tested for quadrature (single channel) excitation *in vivo* [6] and non-quadrature (multi-channel) excitation in a phantom study [7]. This study adapts B1-based SAR determination for non-quadrature excitation *in vivo*. To this goal, the local SAR in thighs and pelvis of a volunteer is investigated and compared with results of corresponding FDTD simulations based on the same volunteer.

Theory: From the polarized magnetic field $\underline{H}^+ = H^+ \exp(i\tau)$ of a given RF excitation, the electric properties $\underline{\kappa} \equiv \varepsilon - i\sigma/\omega$ (ε = permittivity, σ = conductivity, ω = Larmor frequency) of the investigated body area can be estimated using "Electric Properties Tomography" (EPT), see Eq. (1) [5,8,9]. Subsequently, the corresponding local SAR distribution can be estimated using Eq. (2) [5-7]. The required transmit amplitude H^+ can be mapped with standard B1 mapping techniques. The phase τ has to be extracted from the measured "transceive" phase $\varphi = \tau + \rho$ of a standard MR image containing the contributions τ from RF transmission (TX) and ρ from RF reception (RX). To this goal, the transceive phase of a quadrature TX/RX image is (after unwrapping) divided by two to estimate the quadrature RX phase ρ_0. This estimated ρ_0 is subtracted from the transceive phases $\varphi_{n0} = \tau_n + \rho_0$ of images acquired with a single TX channel n and quadrature reception, yielding τ_n. Last, the RX phases ρ_n can be extracted from the transceive phases $\varphi_{nn} = \tau_n + \rho_n$ using the individual channel n for both, TX and RX. The amplitude H_n^- is estimated by suitably mirroring the amplitude of H_m^+ assuming sufficient symmetry of coil array and anatomy. In this study, H_{zn} is neglected $H_{zn} = 0$.

$$\omega^{-2}\mu^{-1} \oint_{\partial V} \nabla \underline{H}^+ \mathrm{d}\mathbf{a} \Big/ \int_V \underline{H}^+ \mathrm{d}V = \underline{\kappa} \quad (1)$$

$$\mathrm{SAR} \sim \sigma \underline{\vec{E}}^2 = \sigma \left(\nabla \times \underline{\vec{H}} / \omega \underline{\kappa} \right)^2 \quad (2)$$

Methods & Results: The described SAR mapping method was tested using a 3T system (Philips Achieva, Best, Netherlands), equipped with an RF body coil of 8 independent TX/RX elements [10,11]. B1 amplitude mapping was performed using the Dual Refocusing Echo Acquisition Mode (DREAM) [12], which is based on the simultaneous readout of STEAM and FID signals, measuring 20 slices of the 8 TX elements in 25s (voxel size 7×7×10 mm³). DREAM also yields the transceive phase free of off-resonance effects [12]. $\underline{H}_n^+$ and $\underline{H}_n^-$ has been estimated as described above, and the local SAR in thighs and pelvis of a volunteer has been determined via Eq. (2) on a standard PC (CPU time = 20s) (Fig. 1). The results have been compared with corresponding FDTD simulations based on the same volunteer (Fig. 2).

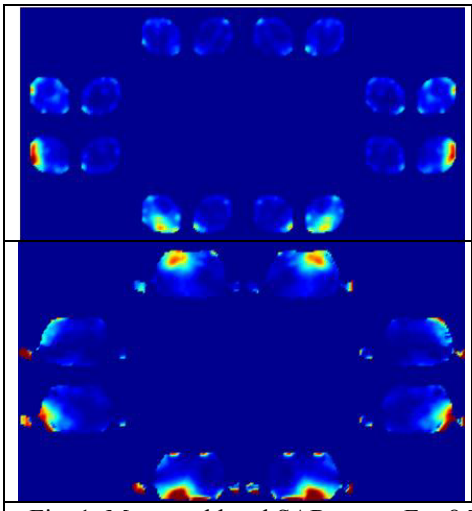

Fig. 1: Measured local SAR maps. For 8 TX array elements, the thighs / pelvis (above/below) of a volunteer are shown.

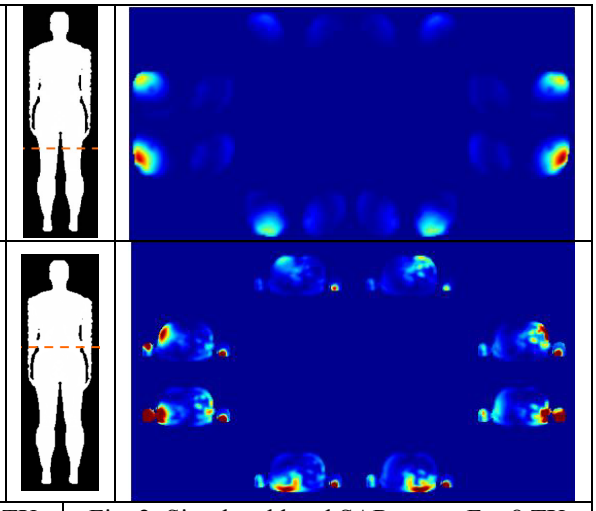

Fig. 2: Simulated local SAR maps. For 8 TX array elements, the thighs / pelvis (above/below) of a volunteer are shown.

Discussion & Conclusion: The high agreement between simulated and experimental results underlines the feasibility of the proposed method to map local SAR for single TX elements *in vivo*. In contrast to earlier studies [5-7], DREAM [12] allows to map both, B1 amplitude and B1 phase, in a single scan. The very short scan time of DREAM, together with the fast SAR reconstruction, opens a chance to estimate SAR patient-individually prior to each MR scan. The SAR of the DREAM sequence is ~20% of the maximally allowed SAR, and thus, below the critical range. It is expected that the presented SAR estimation of the single TX channels enables also the SAR estimation for arbitrary TX channel combinations applied for RF shimming. Future studies have to clarify the impact of the different assumptions made in this SAR mapping method.

References: [1] Graesslin I et al., ISMRM 14 (2006) 2041 [2] Seifert F et al., JMRI 26 (2007) 1315 [3] Collins CM et al., MRM 40 (1998) 847 [4] Homann H et al., MRM, e-publ. May 2011 [5] Katscher U et al., IEEE Trans Med Imag 28 (2009) 1365 [6] Voigt T et al., ISMRM 18 (2010) 2865 [7] Katscher U et al., ISMRM 19 (2011) 494 [8] Haacke EM, Phys Med Biol 38 (1991) 723 [9] Voigt T et al., MRM 66 (2011) 456 [10] Graesslin I et al., ISMRM 14 (2006) 129 [11] Vernickel P et al, MRM 58 (2007) 381 [12] Nehrke K et al., subm. to MRM