Experimental estimation of local SAR in a multi-transmit system

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Introduction: SAR management is a widely discussed topic at main fields of 3T or above, particularly in the framework of multi-transmit systems [1,2]. Typically, local SAR is estimated via patient model simulations, i.e., extensive numerical calculations not suitable for clinical routine. An alternative way to estimate local SAR might be given by "Electric Properties Tomography" (EPT), i.e., the analysis of the RF coil's spatial transmit and receive sensitivity distribution [3]. However, this approach assumes a dominant positive circular magnetic field component $H^+ >> H^-$ of the RF coil used, which is usually only fulfilled for birdcage-type coils in the quadrature mode. For multi-transmit systems, this assumption can be violated, particularly while performing RF shimming. RF shimming, i.e., the adjustment of amplitudes and phases of the different transmit channels to obtain a homogeneous total B1 field, makes use of all available birdcage modes, and thus, yields H^- in the same order of magnitude as H^+. This study investigates the possibility to circumvent this problem by a suitable handling of the acquired sensitivities, potentially opening a short and easy way of local SAR determination in multi-transmit systems.

$$\frac{\oint_{\partial A_{xz}} \left\{\left(-\partial_z H_y(\mathbf{r})\right), \left(\partial_x H_y(\mathbf{r}) - \partial_y H_x(\mathbf{r})\right)\right\} \cdot \mathrm{d}\mathbf{r}}{\mu\omega \int_{A_{xz}} H_y(\mathbf{r}) \mathrm{d}\mathbf{a}_{xz}} \approx \omega\varepsilon(\mathbf{r}) - i\sigma(\mathbf{r}) \quad (1)$$

$$\nabla \times \mathbf{H}(\mathbf{r}) / (i\omega\varepsilon(\mathbf{r}) + \sigma(\mathbf{r})) = \mathbf{E}(\mathbf{r}) \quad (2)$$

$$SAR_{local}(\mathbf{r}) \sim \sigma(\mathbf{r})\mathbf{E}^2(\mathbf{r}) \quad (3)$$

$$2H^+(\mathbf{r}) = H_x(\mathbf{r}) + iH_y(\mathbf{r}), \quad 2H^-(\mathbf{r}) = H_x(\mathbf{r}) - iH_y(\mathbf{r}) \quad (4)$$

$$H^+_{tot}(\mathbf{r}) = \sum_{n \le N} A_n H^+_n(\mathbf{r}) \quad (5)$$

$$H^-_{tot}(\mathbf{r}) = \sum_{n \le N} A_n H^-_n(\mathbf{r}) \approx \sum_{n \le N} A_n \left(H^+_n(\mathbf{r})\right)^* \quad (6)$$

Theory: Electric conductivity σ and permittivity ε can be estimated via Eq. (1), a combination of Ampere's and Faraday's law, with ω the Larmor frequency, A_{xz} a coronal integration area and ∂A_{xz} the boundary of this area [3]. Equation (1) holds inside compartments with constant ε and σ and assumes $H_z << H_x, H_y$ (usually fulfilled for birdcage-type RF coils). After solving Eq. (1), the electric fields can be derived from Ampere's law (2). Finally, results from Eqs. (1,2) are used to calculate local SAR (3). Cartesian H_x, H_y and circular field components H^+, H^- are related via (4). The positive circular components H^+_n of the $n = 1 \ldots N$ different transmit elements are equivalent to the corresponding transmit sensitivities, and thus, can be measured with standard B1 mapping techniques. They are superposed to the total field using the shim weights A_n of the transmit channels (5). The corresponding negative circular component H^-_{tot} is negligible in the quadrature mode of the transmit array, corresponding to a standard single channel quadrature coil. However, for RF shimming using multiple, independent transmit channels, all possible coil modes are active, and H^-_{tot} is not negligible any more. Since no exact determination of H^-_{tot} is known up to now, it is approximated in this study via switching the coil array polarization (6). For RF shimming, the B1 maps of all transmit channels are acquired in a pre-scan preparation phase, allowing the off-line determination of the two circular components of $\mathbf{H}_{tot}$ (5,6) for all possible sets of A_n. The assumption of Eq. (6) is valid for empty RF coils, and increasingly violated with increasing Larmor frequency as well as increasing permittivity and conductivity of the investigated body part. The impact of assumption (6) on the reconstructed local SAR is the central topic of this study.

Methods/Results: A bi-cylindrical phantom (∅ = 7.5cm, height=13cm, distance=12.5 cm) was built with $\varepsilon_r = 81$ in both and $\sigma = 0.5$ (2.5) S/m in the left (right) cylinder. It was placed in the iso-center of an 8-element Tx/Rx body coil [4,5] using a 3T MR system (Philips Achieva, Philips Medical System, Best, The Netherlands). The transmit sensitivities H^+_n of the $N = 8$ transmit channels have been measured using an inverted version of "Actual Flip angle Imaging" [6,7] (TR1/TR2/TE=25/125/3 ms, α=50°, voxel size 2×2×5 mm^3). Then, for the two cases without and with RF shimming, local SAR has been reconstructed using Eqs. (1-3) for H^-_{tot} neglected and approximated with Eq. (6). Fig. 1 compares the resulting local SAR reconstructions with the correct local SAR obtained from corresponding simulations [8].

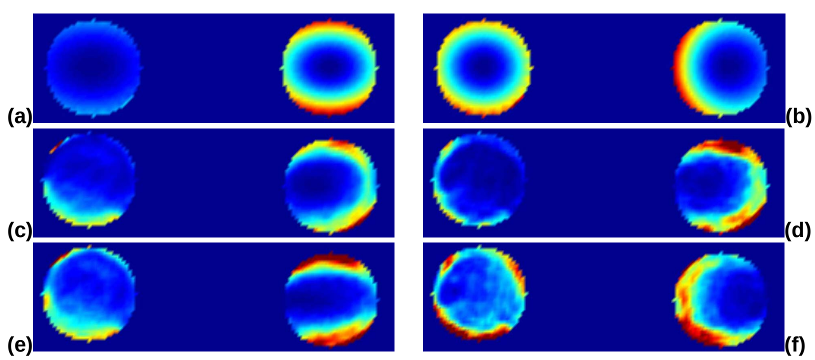

Fig. 1. Local SAR (3). (a) Simulation without and (b) with RF shimming, (c) reconstruction neglecting H^-_{tot} without and (d) with RF shimming, (e) reconstruction approximating H^-_{tot} via (6) without and (f) with RF shimming.

Discussion / Conclusion: In the quadrature mode, i.e., without RF shimming, the neglection of H^-_{tot} does not influence the reconstructed local SAR as expected due to $H^-_{tot} \approx 0$. However, applying RF shimming, the local SAR reconstructed with an approximated H^-_{tot} is significantly closer to the correct local SAR than neglecting H^-_{tot}. If this finding can be confirmed *in vivo*, it might open a short and easy way of local SAR determination in multi-transmit systems.

References: [1] Graesslin I et al., ISMRM 14 (2006) 2041 [2] Nistler J et al., ISMRM 15 (2007) 1027 [3] Katscher U et al., ISMRM 16 (2008) 1191 [4] Graesslin I et al., ISMRM 14 (2006) 129 [5] Vernickel P et al., MRM 58 (2007) 381 [6] Yarnykh VL, MRM 57 (2007) 192 [7] Nehrke K et al., ISMRM 16 (2008) 353 [8] CONCEPT II, Technical University Hamburg–Harburg, Department of Theoretical Electrical Engineering, Germany