Patient-specific *in vivo* local SAR Estimation and Validation

T. Voigt[1], H. Homann[1], U. Katscher[2], and O. Doessel[1]
[1]Institute of Biomedical Engineering, University of Karlsruhe, Karlsruhe, Germany, [2]Philips Research Europe, Hamburg, Germany

Introduction: Tissue heating and local Specific Absorption Rate (SAR) is a major problem for high field MRI, particularly when using multiple transmit channels. In the framework of Electric Properties Tomography (EPT), the local SAR is estimated based on a B1 map [1]. Recently, first preliminary low resolution *in vivo* SAR images were obtained [2]. In this study, B1-based local SAR is determined *in vivo* and validated using FDTD simulations. The impact of neglecting the magnetic field components other than B1 is investigated. The presented approach yields a sufficiently accurate and patient-specific local SAR measurement.

Theory: Assuming constant tissue density, the local SAR is given by Eq. (1). Thus, for determining local SAR, electric conductivity σ and the electric field vector **E** are required. The electric properties σ and ε can be obtained from the complex magnetic field vector **H** according to Eq. (2) [1]. In Eq. (2), ∂A is a closed path around a 2D area with constant $\kappa = \varepsilon - i\sigma/\omega$. For a determination of electric properties, all three complex components of **H** are needed in Eq. (2). Since A is an arbitrarily orientated surface, this additional degree of freedom can be used to further reduce the required input quantities. Writing Eq. (2) for the A_{yz} surface and integrating along the x-direction yields Eq. (3). Hence, the dielectric properties κ can be calculated exactly from the measured B_1^+ fields only.The electric fields **E** are related to the magnetic field vector and the electric properties as stated in Ampere's law. However, to exactly determine **E**, all three complex components of **H** are required.

$$SAR(\mathbf{r}) = \tfrac{1}{2}\sigma(\mathbf{r})\left|\mathbf{E}(\mathbf{r})\right|^2 \quad (1)$$

$$\oint_{\partial A} \nabla\times\mathbf{H}(\mathbf{r})\mathrm{d}\mathbf{l} \Big/ \omega^2\mu\int_A \mathbf{H}(\mathbf{r})\mathrm{d}\mathbf{a} = \kappa(\mathbf{r}) \quad (2)$$

$$-\oint_{\partial V} \nabla\underline{B}_1^+(\mathbf{r})\mathrm{d}\mathbf{a} \Big/ \omega^2\mu\int_V \underline{B}_1^+(\mathbf{r})\mathrm{d}V = \kappa(\mathbf{r}) \quad (3)$$

$$SAR(\mathbf{r}) = \tfrac{1}{2}\sigma(\mathbf{r})\left|\nabla\times\mathbf{H}(\mathbf{r})/i\omega\kappa(\mathbf{r})\right|^2 \approx \tfrac{1}{2}\sigma(\mathbf{r})\Big/\mu\omega^2\left|\kappa(\mathbf{r})\right|^2\left[2\left|\partial_z\underline{B}_1^+\right|^2 + 4\left|\partial_y\underline{B}_1^+\right|^2 + 4\left|\partial_x\underline{B}_1^+\right|^2 - 8\Re\left(\partial_x\underline{B}_1^+\partial_y\underline{B}_1^{+*}\right)\right] \quad (4)$$

In the second step of Eq. (4), all other magnetic field components except for B1 have been neglected, due to $\underline{B}^-, \underline{B}_z \ll \underline{B}_1^+$ usually found for quadrature volume coils. This approximation is tested in the following experiments.

Subjects and Methods: 1) Coronal images of a healthy volunteer have been obtained using a TX/RX head coil in a 1.5T MR scanner (Philips Healthcare, Best, The Netherlands). 15 slices were acquired in 3D acquisition mode with resolution 1.25 × 1.25 × 5 mm³. A B_1^+ map was obtained using a MTM sequence [3] with $TR_{11,12}$ = 30/350 ms, $TR_{21,22}$ = 30/215 ms, and $TR_{31,32}$ = 30/230 ms. For B1 phase mapping, a SE sequence (TE/TR = 6.5/150 ms, α = 90°) was used. The corresponding phase was divided by two to separate transmit from receive phase [1]. Local SAR has been reconstructed using Eq. (4), based on electric properties determined via Eq. (3). 2) For comparison, a FDTD simulation was performed ("XFDTD", Remcom Inc., USA). To this goal, a whole head FFE scan was segmented into grey matter, white matter, CSF, and bone. The resulting model was used as input for FDTD calculations, together with a suitable coil model. Local SAR was reconstructed using the exact expression Eq. (1) and the B1 based approximation Eq. (4).

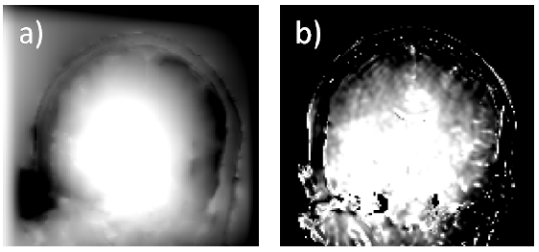

Fig. 1: B1 maps from FDTD simulation (a) and measured using MTM sequence (b).

Results/Discussion: B1 maps from simulation and experiments show a correlation of 80% (Fig. 1). FDTD simulation results are shown in Figs. 2a and 2b. From the FDTD calculations, it can be deduced that local SAR estimation based on B1 only yields sufficient accuracy (correlation of 97%). *In vivo* local SAR estimation is shown in Fig. 2c. A high agreement between *in vivo* and corresponding FDTD local SAR reconstruction can be found.

Conclusion: In this work, an estimation of *in vivo* local SAR based on standard B1 mapping is presented and validated. This approach allows obtaining a patient-specific measurement of local SAR with sufficient accuracy, as has been demonstrated by the comparison with a patient-individual FDTD model. In future work, a more careful segmentation would be useful to deal with the remaining *in vivo* / model deviations.

References: [1] Katscher U. et al., IEEE TMI 28 (2009), 1365-1374. [2] Voigt T. et al., ISMRM (2009), 4513. [3] Voigt T. et al., ISMRM (2009), 4543.

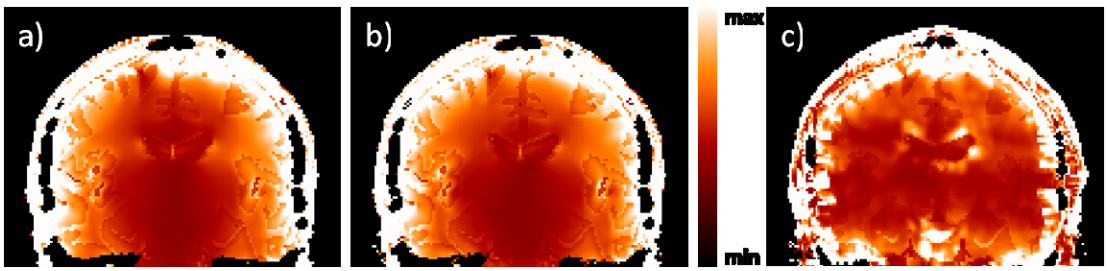

Fig. 2: Local SAR reconstructed from FDTD simulations using the exact formula (a) and the B1 based approximation (b). *In vivo* local SAR reconstruction is shown in (c).