Uncertainties of local SAR determination in parallel transmission MRI

Frank Seifert[1] and Bernd Ittermann[1]
[1]*Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany*

Introduction and Motivation

Controlling local SAR during parallel transmission (pTX) MRI is crucial for patient safety. Using comprehensive electromagnetic field (EM) simulations maximum values of local SAR can be predicted from measured driving conditions, i.e. amplitudes and phases of transmitter voltages derived from calibrated directional couplers. To reduce computational efforts data compression methods like 'Virtual Observation Points' (VOPs) [1] can be applied allowing determination of local SAR in real time. However, due to differences between the model used in the EM simulation and the actual coil loaded by a human subject, it is not a priori clear whether this approach is sound enough to base a patient safety upon it. In order to determine possible limitations of determining local SAR from directional coupler measurements we calculated the maximum local SAR values for a 7T 8-channel transmit/receive head coil using either a phantom or an adult in-vivo model and considered two different internal coil losses.

Materials and Methods

FDTD simulations were performed for an 8-channel shielded loop coil array (Rapid Biomedical) at 300 MHz using XFDTD 6.4 (Remcom Inc.) with an equidistant mesh (2mm), 8 million FDTD cells, current sources and CW excitation. Complex valued 3D steady state complex E, H and J field vector amplitudes were calculated for each driving port. Co-simulation was applied to tune and match the elements to 50 Ω using a T-type matching circuit. Intrinsic coil losses were introduced by an additional resistor R_{coil} of the matching circuit. With R_{coil} = 3 Ω a value of $Q_{unloaded}/Q_{loaded} \approx 2$ was obtained. Either a cylindrical phantom ($d = l$ = 20 cm, ε=76, σ=0.33 S/m) or a realistic in vivo head model ('Duke' from the Virtual Family, IT'IS-Foundation) was used. For each voxel at position $\boldsymbol{r}$ the 8x8 matrix $\boldsymbol{S}(\boldsymbol{r}) = \langle \boldsymbol{j}^*(\boldsymbol{r})\boldsymbol{E}(\boldsymbol{r})\rangle_{10g}$ was calculated from all 3D field components. Assuming a mass density of 1 g/cm^3, the local SAR is given by $\langle u|\boldsymbol{S}(\boldsymbol{r})|u\rangle \times$ m^3/2000kg where $|u\rangle$ is a (dimensionless) 8-component voltage vector with a forward power P_{fwd} proportional to $\langle u|u\rangle$. In contrast to [1], VOP calculation was modified by counting all matrices $\boldsymbol{S}(\boldsymbol{r})$ which are dominant with respect to an offset of 10% of the worst case value (global maximum of all eigenvalues). Using the VOP's maximum local SAR values were calculated for 100000 randomly chosen driving voltage vectors $|u\rangle$ which can be measured directly by calibrated directional couplers.

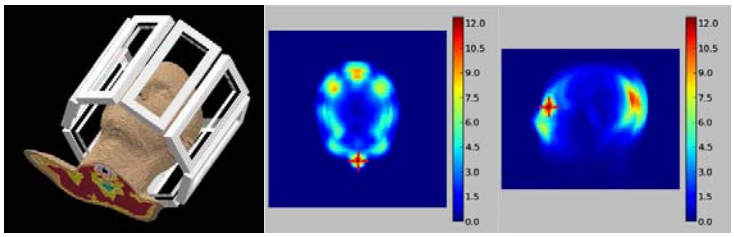


Fig.1: 7T 8-channel Tx/Rx-coil, 'Duke' (l.), largest eigenvalue of $\langle \mathbf{j}^*\mathbf{E}\rangle_{10g}$ in W/kg, P_{fwd}=2.5 W, central axial slice (m.), central sagittal slice (r.)

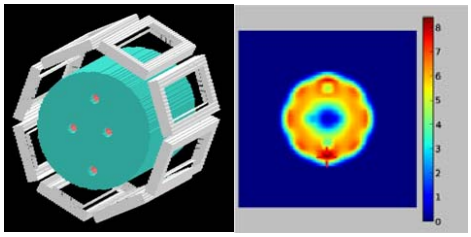


Fig.2: 7T 8-channel Tx/Rx-coil, phantom (l.), largest eigenvalue of $\langle \mathbf{j}^*\mathbf{E}\rangle_{10g}$ in W/kg, P_{fwd}=2.5 W, axial slice (r.)

Results

Distributions of the largest eigenvalue of $\boldsymbol{S}(\boldsymbol{r})$ in slices including the 'worst case' (red cross) are shown in Fig.1 ('Duke') and Fig.2 (phantom). The number of VOPs needed to stay within a 10% SAR offset is much larger for the phantom than for the in-vivo model indicating that SAR hotspots are often associated with anatomical landmarks (Fig. 3). Nevertheless, the 'worst case' values are very similar for both the phantom and the anatomical model. In Fig.4 it is shown that a considerable scatter of predicted local SAR values arises from model changes, presumably due to phase alterations of the coil currents. It is also clearly visible that only very specific, and hence statistically improbable, driving conditions are needed to give the worst case.

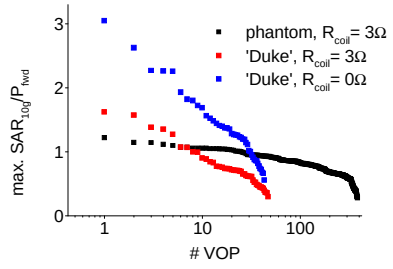
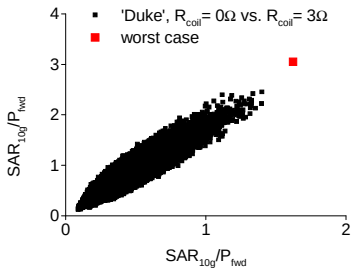


Fig.3: calculated VOPs with (phantom, 'Duke') and without ('Duke') realistic coil losses



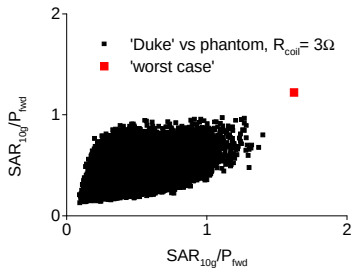


Fig.4: scatter plots of max. local SAR for 2 different coil loss assumptions using 100000 randomly chosen voltage vectors. Left 'Duke' vs. 'Duke'. Right: 'Duke' vs phantom

Conclusions

Local SAR prediction in pTX MRI based on real-time multi-channel driving voltage measurements with directional couplers are prone to model variations even when the 'worst case' values for different models a similar. Hence, when aiming to go beyond (i.e. below!) 'the worst case' scenario for patient safety in pTx MRI, even the careful validation of simulation results including the variability 'real life applications' is already a challenging task.

References

[1] G. Eichfelder, M. Gebhardt, Mag. Reson. Med. 66 (2011) 1468-1476