A practically feasible approach to SAR-constrained patient-specific B1+ shimming in 7T head imaging based on generic SAR behavior.

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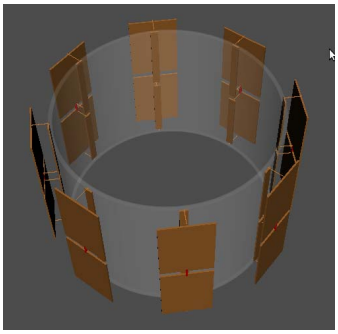
Purpose: The use of patient-specific radiofrequency (RF) shim sets to mitigate B_1^+ inhomogeneity in high-field MRI requires on-line, patient-specific monitoring of the specific absorption rate (SAR). Numerical simulation is currently the most effective way to do so as the electric fields required for this evaluation cannot be measured directly. These simulations however require a dielectric model of the patient, which largely complicates the clinical work-flow if this needs to be done on an individual basis. For this reason, generality in the SAR distribution during MRI of the head is investigated to evaluate whether a generic model can be used as a practical alternative.



Methods: Electric and magnetic fields were simulated for an 8 channel parallel transmit array [1] with an in-house developed GPU implementation of the finite-difference time-domain algorithm. The array was loaded with 6 different voxel models of the head (2mm isotropic) constructed from detailed manual segmentations. The studied population consists of the adult Virtual Family models Ella and Duke, the infants Louis and Billie [2] and an adult male and female Japanese model [3]. First, generic SAR behavior was studied through comparison of the largest eigenvalue distributions following from the local power kernel matrices [4]. Second, two types of numerical RF shimming experiments were performed: experiments with and without local and global SAR constraints. During these experiments, patient specific B_1^+ maps were used as these can be measured in clinical practice. In the SAR-constrained shimming experiments, SAR values were computed based on a generic model that was selected in turn from the 6 head models. This resulted in 5 shim sets per model in the population.

Results: The largest eigenvalue distribution was comparable between models, indicating general SAR behavior. The contribution of the different elements was clearly reflected. RF shimming without SAR constraints resulted in a moderate improvement in $|B_1^+|$ homogeneity relative to quadrature excitation at the cost of a substantial increase in the local SAR (>100%) and (>70%) global SAR. Imposing IEC based SAR constraints during optimization, where SAR levels were estimated using the generic SAR model, is an effective shimming strategy as SAR levels are strongly reduced at the cost of a minimal increase in $|B_1^+|$ heterogeneity. A safety factor of 1.4 covers for anatomical variation in the studied population.

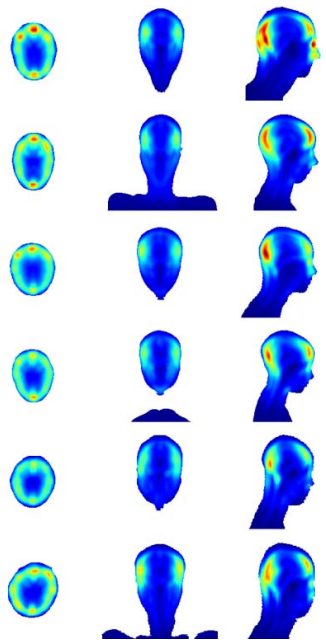


Figure 1: Cross-sections of the largest eigenvalue distribution for the 6 models indicating common SAR behavior.

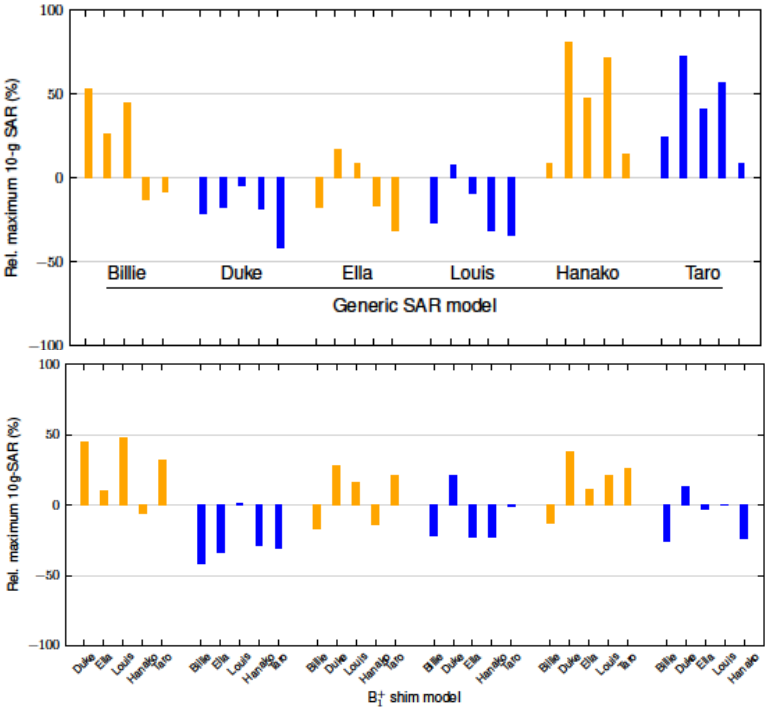


Figure 2: SAR predicted by the generic model relative to SAR according to a patient-specific model after shimming without (top) and with (bottom) SAR constraints. Positive numbers correspond to over-estimation by the generic model. SAR levels during optimization, if applicable, are evaluated for the generic model, selected in turn from the population. For SAR-constrained shimming, a reduction in the amount of under- estimation and over-estimation is observed relative to unconstrained shimming.

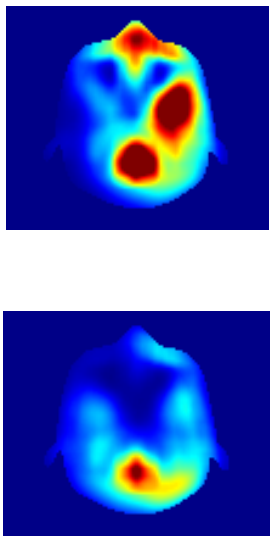


Figure 3: 10g-SAR distribution for the Billie model after shimming without (top) and with (bottom) SAR constraints. The generic model used during constrained shimming was Duke.
(blue: 0W/kg, red ≥10W/kg)

Conclusions: Generic SAR behavior in 7T imaging of the head makes generic SAR models a practically feasible alternative to patient-specific SAR models. Based on the results acquired for the studied population, a moderate safety factor is sufficient to account for under-estimation of the local SAR in reality. Shimming with SAR constraints, evaluating SAR levels on a generic SAR model, delivers shim sets with local and global SAR levels compliant with IEC SAR norms at a minimal increase in $|B_1^+|$ inhomogeneity relative to shimming without SAR constraints.

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