Matrix and Model Order Reduction Approach for Rapid Safety Prediction and Supervision of Local and Global SAR in Parallel Transmit Coils

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Introduction

MR systems for human use set limits on the whole-body specific absorption rate (wbSAR) as defined by regulatory committees to ensure patient safety. For circularly polarized (cp) mode this generally ensures safe peak spatial average SAR (psSAR). Care has to be taken with the promising parallel transmit (pTx) coil technology as recent studies have shown that it has the potential to increase the psSAR to wbSAR ratio by more than one order of magnitude [1]. The energy deposition depends strongly on the excitation of the coil channels and on the patient's anatomy, posture, and position. In order to safely benefit from the flexibility offered by pTx technology, methodology that allows rigorous assessment of the wbSAR and psSAR in an appropriate examination workflow on an individual patient basis is required. This study introduces an approach that for a reference anatomy permits rapid determination of these quantities for any channel excitation, using pre-computed information. The mapping of a specific patient to one of the pre-computed reference anatomies is not covered here. The method is applied to a detailed female model with variable obesity levels.

Theory

Local SAR is defined as a function of the rms E-field, E, as well as the conductivity and the density of the material, σ and ρ, respectively. In a birdcage coil for example, the total E-field is produced by the superposition of the contributions of each independent coil rung of complex amplitude c_i and the SAR can be written as (1). The most relevant quantity in a safety-assessment context is not the local SAR but rather the SAR averaged over a volume V (typically over a 1 g or 10 g cubical volume, or over the whole-body). The averaged SAR, SAR_V, can be written as (2), with M_{ij} containing the interference term between the E-field contributions from two rungs, as defined in (3). Based on simulated field distributions such matrices can be computed for each location in the body and the local SAR for the excitation parameters c_i is obtained by evaluating the corresponding quadratic form. As there are still too many quadratic forms to evaluate to find the psSAR for high resolution models, a model order reduction approach is employed: using a variant of the method from [2] matrices of locations that show similar behaviour within a specified tolerance are lumped into (far less) 'Virtual Observation Points'.

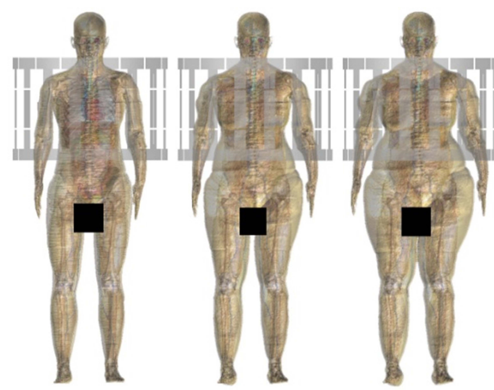

Figure 1: Coil (16 rungs and a shield) containing Ella with different obesity levels.

$$SAR = \frac{\sigma}{\rho}\left|\sum_i c_i \vec{E}_i\right|^2 \qquad (1)$$

$$SAR_V = \frac{\int_V \frac{\sigma}{\rho}\left|\sum_i c_i \vec{E}_i\right|^2 \rho dV}{\int_V \rho dV} = \sum_{i,j} c_i c_j^* M_{ij} \qquad (2)$$

$$M_{ij} = \frac{\int_V \sigma E_i^* \cdot E_j^* dV}{\int_V \rho dV} \qquad (3)$$

Methods

Using FDTD simulations, the method was applied to a 3 T coil model with 16 individually fed rungs, tuning elements and an RF shield. The simulations of the incident fields were performed independently for each rung. The detailed anatomical 'Ella' model from the Virtual Family [3] was inserted and morphed to four different BMI values by performing a mechanical simulation with an expanding force assigned to different fat tissues, rigid bones and other tissues that passively deform. 40,000-60,000 averaged SAR matrices (16x16) were determined per setup and the model order reduction algorithm applied.

Results

For a tolerance of 5-20% of worst-case psSAR a model reduction of 99.7-99.97% could be obtained. Validation with 100 random excitations showed that the estimations are conservative and overestimation never exceeds the tolerance. The wbSAR and psSAR correlate with the BMI. This can be explained by the increasing cross-section perpendicular to the field, which allows for larger eddy-currents. psSAR normalized to wbSAR was nearly independent of BMI for circular polarization excitation.

Conclusions

The proposed approach allows a promisingly rapid evaluation during a scan sequence to enable an efficient safety prediction and online supervision of local and whole-body SAR for any pulse sequence in multi-channel pTx coils, provided that a suitable and reliable mapping of a specific patient to one of the reference models can be achieved. The positioning and posture dependency, BMI dependence for non cp mode, required number of reference models (incl. safety margin) and the mapping of patients to reference models still have to be investigated further.

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[3] Christ, et al., The virtual family – development of surface-based anatomical models of two adults and two children for dosimetric simulations, *Phys. Med. Biol.,* 55(2):N23, 2010.