Evaluation of maximum local SAR for parallel transmission (pTx) pulses based on pre-calculated field data using a selected subset of "Virtual Observation Points"

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Introduction

One of the current major obstacles for parallel transmission [1] (pTx) applications in MRI is the management of local SAR. The current method of choice is electromagnetic simulation of the impact of parallel RF pulses to suitable body models [2-5]. This approach presents two major challenges: *i)* the match between the numerical body model and the human subject; and *ii)* the complexity of the spatial distribution of SAR due to the independent transmission signals superposing inside the human body. In this work we address the complexity problem inherent in local SAR estimation and show that a relatively small subset of carefully selected "virtual observation points" is adequate for prediction and control of maximum local SAR in pTx.

Methods

Signal- and space-dependent contributions to local SAR of a particular voxel *v* can be separated by expressing the power density $\dot{q}_v$ as

$$\dot{q}_v(t) = \mathrm{Re}(\bar{\vec{E}}_v(t) \cdot \underline{\underline{\sigma_v}} \cdot \vec{E}_v(t)) = \mathrm{Re}\left(\sum_{k=1}^{N}\sum_{l=1}^{N}\left(\bar{U}_k(t) \cdot U_l(t)\right)\left(\bar{\vec{S}}_{k,v} \cdot \underline{\underline{\sigma_v}} \cdot \vec{S}_{l,v}\right)\right)$$

Here, $U_k(t)$ denotes the complex-valued signal of transmit channel *k*, $\vec{S}_{k,v}$ is the pre-calculated electrical field vector that is caused by a unit signal of channel *k* in voxel *v*, *N* denotes the number of transmit channels and $\underline{\underline{\sigma_v}}$ denotes the complex conductivity tensor at the voxel *v*. The matrices $S_v = (S_{k,l})_v := \bar{\vec{S}}_{k,v} \cdot \underline{\underline{\sigma_v}} \cdot \vec{S}_{l,v}$ can be precalculated for the desired size of the local region (e.g. 10g).

In order to ensure that local SAR of a particular pTx excitation stays within upper limits [6] over the whole model, the related maximum power deposition has to be determined for the applied signal vectors U. Instead of inspecting all voxel matrices of the model, a much smaller sub-set of matrix elements has been pre-compiled that still offers a good estimate of peak SAR in the full model by removing essentially redundant matrix elements from the set of matrices under consideration for SAR evaluation. Local SAR of physiologically critical areas with respect to SAR can be scaled up prior to this compression step in order to increase the sensitivity of their evaluation, or their inclusion in the set of "virtual observation points" can be enforced independently.

We tested the performance of the proposed algorithm to detect local SAR maxima by comparison with an exhaustive search over local SAR distribution in numerical simulations of adult male and female subjects (Virtual Family [7]) and the HUGO models (Medical VR Studio, Lörrach, Germany). The simulation applied 1000 random combinations of signal amplitude and phase in an 8-channel pTx body system at 3T. The spatial resolution of the whole-body models was 7.18 mm, and the electrical fields were estimated with the Transient Solver in Microwave Studio (CST AG, Darmstadt, Germany). The region size for local power density was 10 cm³. Refining the averaging method to upper limits for 10g SAR will result in small changes of the matrices S due to the maximum density values of the body models and is not expected to change the compression quality significantly.

Results

The proposed algorithm successfully predicted the peak local SAR by limiting the evaluation of local SAR to a small sub-set of virtual observation points out of a total of 297897 matrices that are required to reasonably capture every such 10cm³ SAR volume. Figure 1 shows a typical outcome of a statistical test on a HUGO model where the local SAR predictions using 36 virtual observation points cover the full body set.

Conclusions

The proposed method of model compression for local SAR successfully captured regions of local SAR maxima, but with dramatically reduced computation cost compared to an exhaustive search over the complete model. This approach offers practical means to include local SAR estimation and management in pTx RF pulse design, to comprehensively but efficiently compare local SAR properties of different simulation models and to accelerate the local SAR evaluation of RF pulses.

Disclaimer

The concepts and information presented in this paper are based on research and are not commercially available.

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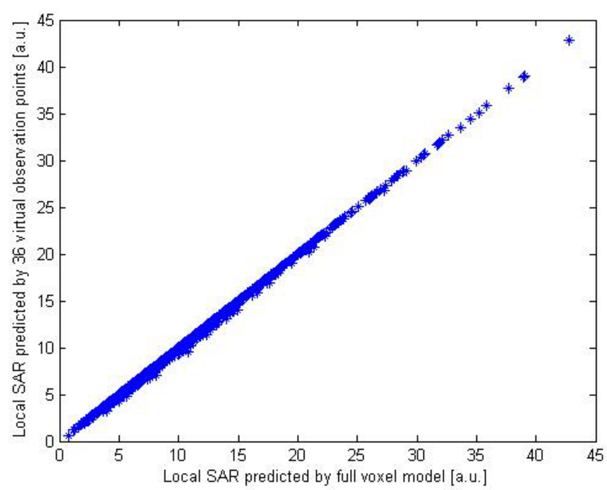

Fig. 1. Local SAR evaluations based on 1000 random 8-channel signal combinations. For each test sample, the SAR results of the full voxel model (exhaustive search) are compared with the results based on the selected 36 virtual observation points.