A comparison of local SAR using individual patient data and a patient template

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INTRODUCTION: Higher field strengths and new multi-coil-transmission methods require special attention regarding the patient safety. An often used approach to determine SAR is electromagnetic field simulation based on the Finite-Difference Time-Domain method (FDTD). This method requires accurate modelling of transmitting elements and the object itself. Due to long computation times, field calculations prior to each scan are hardly feasible and instead the storage of field data for different patient constitutions and body regions is required. Recently an alternative method has been proposed that uses measured B1 data to estimate SAR and electric properties of the object [1]. However, if the distribution of the electric properties is not exactly known for the individual patient, errors are introduced to the SAR prediction. Particularly the fat distribution can differ strongly from patient to patient. As has been reported in the literature, SAR peaks can occur at tissue-fat and tissue-bone interfaces due to their high dielectric contrast [2] [3]. The present work therefore compares the effect of incorrectly assumed patient data in two methods: The standard FDTD method and the method of solving Ampère's law for time harmonic fields (Equ.1) using B1 fields, which will in the following be named Finite-Difference Frequency-Domain method (FDFD).

METHODS: Using the FDTD method (SEMCAD X, Schmid & Partner Engineering AG, Switzerland) electromagnetic fields were calculated for a shielded strip line driven at its resonance frequency of 125MHz. Simulations were performed for two adult phantoms of the Virtual Family Project [4] with an isotropic resolution of 2mm. The phantoms were scaled to make them comparably sized and positioned with the liver above the centre of the coil. The first phantom is in the following treated as the individual patient, the second one serves as a patient template (Fig.1).

$$\bar{\nabla} \times \bar{H} = (\sigma + i\omega\varepsilon\varepsilon_0)\bar{E} \quad (1)$$

$$\mathrm{SAR} = \frac{\sigma}{2\rho}\left|\bar{E}\right|^2 \quad (2)$$

Then the simulated transversal components of the magnetic field in the individual patient were used to calculate E by solving Equ.1.
In Equ.1 $\bar{E}$ and $\bar{H} = \bar{B}/(\mu\mu_0)$ are electric and magnetic field strengths and σ, ε and μ are electric conductivity, relative permittivity and permeability of the different tissue types. The electric fields were calculated for the individual patient as well as for a homogeneous phantom (σ=0.352S/m, ε=44.3). The SAR was then evaluated according to Equ.2 for the different situations a)-d) as detailed in the table.

RESULTS AND DISCUSSION: As Fig.2a shows the absorbed power is focused on a region close to the coil, but additionally an SAR peak occurs at a fat-tissue interface with high dielectric contrast. This behaviour strongly depends on the individual fat distribution and did not occur for the patient template (Fig.2b). The results of the FDFD calculations are depicted in Fig.2c and d. Apart from deviations along the phantom boundaries that are due to differences in mesh interpolation, the SAR distribution is reflected very well if absolute information on electric properties is available (Fig.2c). Assuming a homogeneous tissue leads to the SAR distribution shown in 2d. As information on the object is already present in the B1 field the basic shape of the SAR distribution is preserved within each tissue but its absolute value is under- respectively overestimated by a factor resulting from the discrepancy between actual and assumed tissue parameters. This factor takes values of 0.1 and 0.4 for fat and bone and lies in between 1.0 to 3.7 for all other tissues in this body region. Fig.3 shows the SAR profile along the indicated line in Fig.1 for the cases a), b) and d).

	Distribution of electric properties used for simulations	Field calc. method
a)	individual patient	FDTD
b)	patient template	FDTD
c)	individual patient	FDFD
d)	homogeneous tissue (σ=0.352S/m, ε=44.3)	FDFD

CONCLUSION: In this work it was shown that SAR calculations for a patient template using the FDTD method do not necessarily reflect the SAR distribution in the individual patient even if they are equally sized and correctly positioned. In comparison the basic shape of the SAR distribution and the location of peak SAR values that can occur e.g. at interfaces of high dielectric contrast can be determined correctly by using B1 data, even if the real distribution of the electric properties is unknown and a homogeneous tissue is assumed. An appropriate choice of its electric properties results in a general overestimation of SAR and therefore simulates a worst case scenario.

OUTLOOK: The underestimation of SAR in fat and bone could further be avoided by additional measurements of fat distribution, e.g. [5], and bone segmentation. Furthermore it has to be investigated if the accuracy that can be achieved in B1 measurements by MRI in vivo is sufficient to allow proper electric field calculations.

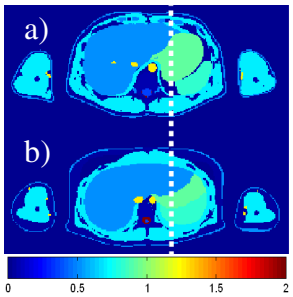

Fig. 1 Distribution of electric conductivity [S/m] in a) individual patient and in b) patient template

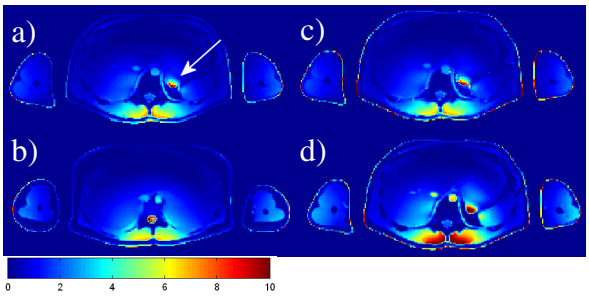

Fig. 2 SAR-distribution [a.u.] in a) individual patient /FDTD, b) patient template/FDTD, c) individual patient/FDFD and d) homogeneous tissue/FDFD; the arrow indicates a SAR peak close to an interface of high dielectric contrast

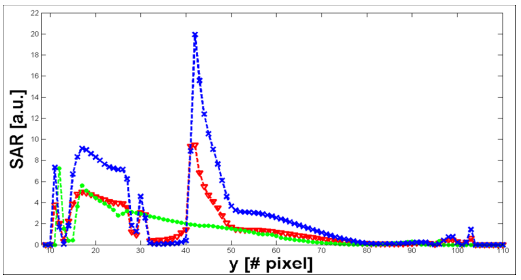

Fig. 3 SAR profile along indicated line in Fig.1; a) individual patient/FDTD (▼), b) patient template/FDTD (●) and d) homogeneous tissue/ FDFD (x);

ACKNOWLEDGEMENT: This work is part of the INUMAC project supported by the German Federal Ministry of Education and Research, grant #13N9208.

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