Quality assessment of B1-based local SAR estimation as a function of position within a parallel transmit coil at 3T

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INTRODUCTION: RF power absorption is a major concern in parallel transmission applications. An established method for determining the specific absorption rate, SAR, is the use of electromagnetic field simulations, however, this method requires accurate modelling of the transmit coil [1] as well as a sufficiently accurate model of the patient and their position [2]. An alternative method for SAR estimation is based on post-processing of the measured transmit field produced by a birdcage-type coil that is operated in quadrature mode for transmission and reception [3-5]. Due to the particular polarization properties in transmission and receive process, the underlying assumptions about the magnetic field components that are not directly measurable via MRI yielded good results. This principle of switched coil polarization between transmission and reception has also been used for SAR estimation in RF shimming with a multi-transmit array [6]. The aim of the present work is to extend the method and investigate its feasibilty of SAR estimation via B1 maps for an 8-channel transmit array designed for parallel transmission at 3T.

THEORY & METHODS: The coupling of time-harmonic electric and magnetic fields produced by the transmit coil is described by Maxwell's equations. If the magnetic field H as well as the conductivity σ and the permittivity ε are known, the electric field E can be calculated via Ampere's law (Eq.1). The magnetic field H, described in a rotating frame reference system, consists of the three components H^+, H^- and H_z with only H^+ being directly measurable via MRI. Conventional transmit coils designed for MRI usually generate transverse magnetic fields. Since the transmit array under investigation is a birdcage-type coil with 8 individual feeding ports [7] we assume $H_z \approx 0$ resulting in $dH_z/di=0$ for all spatial directions $i=x,y,z$. As long as this assumption holds true, the H^+ and H^- equally contribute to E_z as shown by Eq.4. In this study, the static magnetic field B_0 is assumed to point in positive z direction. We therefore replace $H_x = 2H^+$ and $H_y = 2iH^+$ which is valid as long as E_z is the dominating component of the transmit array. Further it is assumed that the modulation of the H^+ fields with an additional phase resulting from the receive process can accurately be corrected.

$$\underline{\vec{E}} = \frac{\vec{\nabla}\times\underline{\vec{H}}}{\sigma + i\omega\varepsilon\varepsilon_0} \quad (1) \qquad \mathrm{SAR} = \frac{\sigma}{2\rho}\left|\underline{\vec{E}}\right|^2 \quad (2)$$

$$\partial_z \underline{H_z} \approx 0 \quad (3a) \qquad \underline{E_z} >> \underline{E_x}, \underline{E_y} \quad (3b)$$

$$\underline{E_z} \propto \left(\partial_x \underline{H_y} - \partial_y \underline{H_x}\right) =$$

$$= \left(\partial_x \left(i\underline{H^+}\right) - \partial_y \underline{H^+}\right) + \left(\partial_x \left(-i\underline{H^-}\right) - \partial_y \underline{H^-}\right) =$$

$$= \frac{1}{2}\left(\partial_x \underline{H_y} - \partial_y \underline{H_x} + i\left(\underbrace{\partial_x \underline{H_x} + \partial_y \underline{H_y}}_{\approx 0 \text{ since } \vec{\nabla}\cdot\underline{\vec{H}} = 0}\right)\right)$$

$$+ \frac{1}{2}\left(\partial_x \underline{H_y} - \partial_y \underline{H_x} - i\left(\underbrace{\partial_x \underline{H_x} + \partial_y \underline{H_y}}_{\text{and } \partial_z \underline{H_z} \approx 0}\right)\right)$$

$$\approx \left(\partial_x \left(2i\underline{H^+}\right) - \partial_y \left(2\underline{H^+}\right)\right) \quad (4)$$

In order to test our method FDTD-based electromagnetic field simulations [8] were performed for the 8-channel transmit array and a human whole body phantom [10] at 3T. Ampere's law was solved for each of the 8 transmit channels separately for E by using i) the full information on the magnetic field H^+, H^- and H_z and ii) H^+ only, $dH_z/di=0$ and $H_x = 2H^+$ and $H_y = 2iH^+$. In both cases a homogeneous tissue with $\sigma=0.70$S/m and $\varepsilon=60$ was assumed leading to limited tissue dependent over- or underestimation of the actual local SAR as described in [11]. The SAR was then calculated according to Eq.2. Results from i) and ii) were compared to the original SAR distribution obtained from FDTD simulations regarding the maximum local SAR and the spatial correlation. The evaluation was done on a slice-by-slice basis along the full length of the transmit array. Mean and standard deviation were calculated from the 8 independent results of the 8 transmit channels.

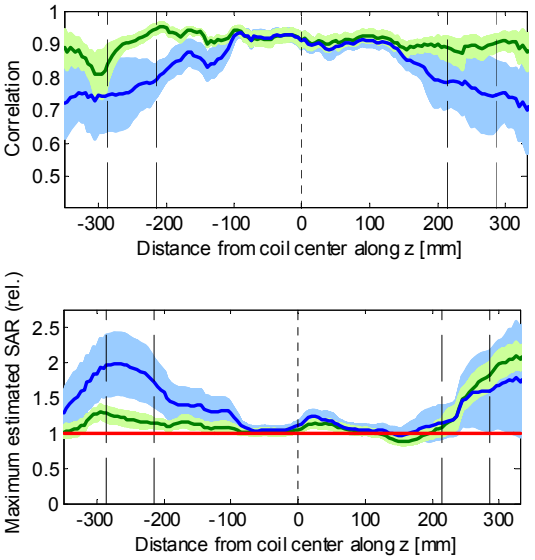

Fig.1 Spatial correlation of actual and estimated SAR (top) and ratio of estimated and actual maximum local SAR (bottom) as a function of z-position within the transmit array. curve: mean over 8 TX channels; coloured area: standard deviation; green: SAR via H^+, H^-, H_z ; blue: SAR via H^+ only

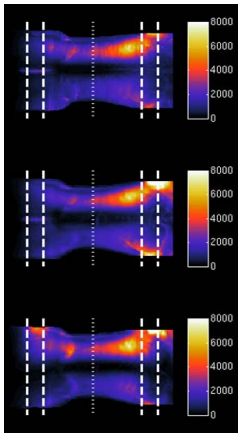

Fig. 2 Maximum intensity projection of SAR [W/kg] in the human whole body phantom in coronal view; shown for channel 1.

top: actual SAR;
middle: SAR via H^+, H^-, H_z ;
bottom: SAR via H^+ only

Position of endrings and coil centre are indicated by dashed/dotted lines

RESULTS & DISCUSSION: Fig.1 shows the spatial correlation and the maximum local SAR compared to the actual SAR from FDTD simulations. Using all H components for SAR estimation (i) only suffers from deviation in the electrical properties and therefore yields a correlation of ~0.9 over the whole z range of the transmit array. Results obtained from using H^+ only (ii) additionally depend on the applicability of the assumptions made on the electromagnetic field components (Eq.3a,b). As the results indicate, they hold true well for the central part of the transmit array over a range of about 20cm leading to an almost identical curve progression compared to i). Only when approaching the endrings whose positions are indicated by the dashed lines ii) significantly deviates from i) due to an increasing influence of H_z. The maximum intensity projection of the SAR is depicted in Fig2. for a coronal view. Regarding the position of the largest hot spots the actual SAR obtained from electromagnetic field simulations (top), the one estimated via full information on H (middle) and the one estimated via H^+ only (bottom) are in good agreement in the central part of the coil. The actual strength of the hot spots shows slight differences which partly originate from the homogeneity assumptions on the tissue distribution. A proper choice of the electrical properties might be used for a conservative estimation of the SAR compatible with safety considerations.

CONCLUSION & OUTLOOK: For the transmit array under investigation a reasonable SAR estimation within the central coil volume is feasible using the presented method. However, further investigations are required regarding different positions of the human inside the transmit array. Furthermore, a method to separate the influence of the receive phase is under investigation.

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