Improving B1-based SAR determination via iterative determination of missing field components

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Introduction: SAR management to ensure patient safety is a central issue of parallel RF transmission [1,2]. The additional degrees of freedom available in parallel transmission hamper straight-forward SAR estimations as applied for single channel transmission. As an alternative to the usually applied model-based SAR estimation (see, e.g., [3,4]), it has been proposed to estimate SAR from individually measured B1 maps [5,6]. Overall, the accuracy of this B1-based SAR determination is satisfying even for multi-channel systems *in vivo* [7], however, could be further increased if the hitherto unknown longitudinal component of B1, H^z, can be determined. This study investigates an iterative estimation of H^z and its impact on the resulting local SAR determination, based on simulations of spherical as well as realistic patient models for a RF body coil with eight independent transmit channels at 3 T.

Theory: To exactly determine local SAR, all three spatial components of the magnetic RF field $\mathbf{H} = \{H^+, H^-, H^z\}$ are required. With MR, only the positive circularly polarized component H^+ of an array element can be measured via B1 mapping (see, e.g., [8,9]). The negative circularly polarized component H^- can be estimated via the receive sensitivity of the array element (see, e.g., [10]) or determined exactly using Local Maxwell Tomography, which additionally yields the phases of H^+ and H^- [11,12]. With this input, an initial magnetic field $\mathbf{H}_0 = \{H^+_{init}, H^-_{init}, 0\}$ can be used to calculate an initial value for the electric field $\mathbf{E}_0$ with Ampere's law (Fig. 1). The additionally required electric conductivity σ and permittivity ε can be determined with Electric Properties Tomography (EPT) [5,13] based on H^+ only. Applying Faraday's law, the magnetic field can be re-calculated. Here, the re-calculated H^+ and H^- are replaced by the original H^+_{init} and H^-_{init}, yielding $\mathbf{H}_1$. Applying Ampere's law again, $\mathbf{E}_1$ can be obtained from $\mathbf{H}_1$, and so on. For each iteration n, a corresponding local SAR_n can be calculated using $\mathbf{E}_n$ and σ obtained with EPT. The error of H^z for iteration n was derived as

$$H^z_n = H^z_{true}\{1-(\partial_x^2+\partial_y^2)^n H^z_{true}/(\partial_x^2+\partial_y^2+\partial_z^2)^n H^z_{true}\}\ , \qquad (1)$$

which ensures the convergence of the iteration.

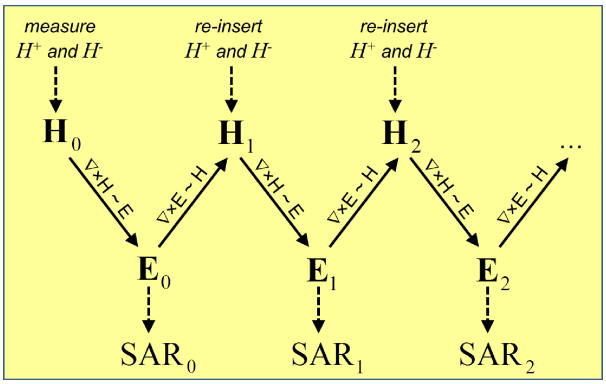

Fig. 1: The missing field component H^z can be iteratively estimated by alternately applying Ampere's and Faraday's law, while re-inserting the known field components in each iteration.

Methods & Results: The described SAR mapping method was tested simulating a RF body coil with 8 independent TX/RX channels at 3 T [14]. A spherical model with ∅ = 20 cm ("Concept II", Technical University Hamburg-Harburg, Germany) and a realistic patient model ("XFDTD MicroCluster", Remcom Inc., USA) have been investigated for all 8 TX elements. Iterating H^z of the spherical model, the mean initial error SAR_0/SAR_{true} of the TX elements ranges from 4.3% to 19.3% (mean 10.6 %), from 2.5% to 12.0% (mean 6.6 %) after the first iteration, and from 1.7% to 8.5% (mean 4.6 %) after the second iteration (Fig. 2a). In the head of the realistic patient model (Fig. 2b), the mean initial error SAR_0/SAR_{true} (averaged over the TX elements) is 11.8 % and reduces to SAR_1/SAR_{true} = 8.2 % after the first iteration. In the liver, no significant H^z has been found, and the iteration has only a negligible effect (mean SAR_0/SAR_{true} ~ mean SAR_1/SAR_{true} ~ 2 %). Furthermore, satisfying results have been obtained also for the case that only H^+ is given and both H^z and H^- are iterated in the described way.

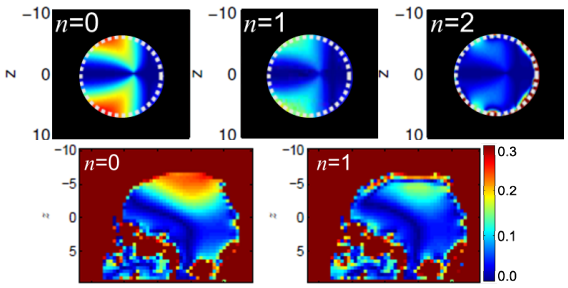

Fig. 2: Relative SAR error SAR_n/SAR_{true} for different iterations n in the spherical model (upper row) and the realistic patient model (lower row) for a single element of the TX array.

Discussion & Conclusion: This study opens a way to enhance the accuracy of B1-based SAR determination. It shows the principle feasibility of estimating missing components by aiming for a magnetic field which satisfies Maxwell's equations. Thus, it could play an important role for RF safety of, e.g., individually placed surface TX arrays. Future studies have to clarify the behaviour of the method for *in vivo* measurements. Of central importance will be a high robustness of numerical differentiation to enable a sufficient number of iterations.

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References: [1] Graesslin I et al., ISMRM 14 (2006) 2041 [2] Seifert F et al., JMRI 26 (2007) 1315 [3] Collins CM et al., MRM 40 (1998) 847 [4] Homann H et al., MRM 66 (2011) 1767 [5] Katscher U et al., IEEE Trans Med Imag 28 (2009) 1365 [6] Voigt T et al., MRM 68 (2012) 1117 [7] Katscher U et al., ISMRM 20 (2012) 2733 [8] Sacolick LI et al., MRM 63 (2010) 1315 [9] Nehrke K et al., MRM 68 (2012) 1517 [10] Wang J et al., MRM 53 (2005) 408 [11] Katscher U et al., ISMRM 19 (2011) 494 [12] Sodickson D et al., ISMRM 20 (2012) 387 [13] Voigt T et al., MRM 66 (2011) 456 [14] Vernickel P et al, MRM 58 (2007) 381