B1-based SAR determination for local RF transmit coils

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Target audience: MR physicists and RF engineers with focus on RF safety / parallel RF transmission

Purpose: SAR management, particularly the prediction of local SAR during scan planning, is a central issue of parallel RF transmission (pTX) to ensure patient safety. SAR is usually estimated based on models, but could alternatively be estimated from individually measured B_1-maps [1-3]. A key issue of this "B_1-based SAR determination" (BBS) is that the longitudinal component of B_1, B_z, cannot be measured via MRI, and thus, suitable estimations for B_z have to be found. Satisfactory results have been reported assuming $B_z = 0$ for TX arrays of rods forming birdcage-type volume coils [1-3]. However, this assumption should be less valid for the upcoming type of TX arrays consisting of local elements ("mattresses"), particularly near transversely oriented parts of conductors. On the other hand, patient-individual SAR determination is of increased interest for these local TX arrays due to their individual placement on the patient. This study investigates different ways for fast and simple B_z modelling and the resulting impact on the corresponding local SAR estimation, based on simulations of elliptic cylinders as well as realistic patient models for single elements of a TX array at 3 T.

Theory: To accurately determine local SAR, all three spatial components of the magnetic RF field $\mathbf{B} = \{B_x, B_y, B_z\}$ are needed to calculate the required electric field $\mathbf{E}$, see Eq. (1). This study focuses on estimating the unknown B_z, i.e., it is assumed that B_x and B_y are known from the (exactly or approximately) determined B_1^+ and B_1^- (see, e.g., [4,5] for B_1^- and numerous studies on B_1^+-mapping), and so are conductivity σ and permittivity ε (see, e.g., [1]). Magnetic permeability μ and mass density ρ are assumed to be constant throughout the patient. Three different approaches to estimate B_z have been tested: (A) Assuming $B_z = 0$ as, e.g., in [1-3]. (B) Simulating B_z for the "empty" loop coil, i.e., without patient model. This can be done once, and the resulting B_z can be subsequently applied for BBS in all scans using this coil. (C) Integrating known B_x and B_y via Gauss's Law, see Eq. (2). This approach requires that the FOV of the BBS scan can be extended in feet-head direction to $z_0(x,y)$ with $B_x(x,y,z_0) \approx B_y(x,y,z_0) \approx 0$, which is a realistic task for the local surface coils regarded.

$$\mathrm{SAR} = \sigma \mathbf{E}^2/(2\rho) = \sigma\left(\nabla\times\mathbf{B}/(\mu\sigma + i\omega\mu\varepsilon)\right)^2/(2\rho) \qquad (1)$$

$$B_z(x,y,z) = -\int_{z_0(x,y)}^{z} \partial_x B_x(x,y,z') + \partial_y B_y(x,y,z')\,dz' \qquad (2)$$

Methods: The three described approaches to estimate B_z have been tested in two different scenarios. First, a circular loop coil (f = 128 MHz, ∅ = 20 cm) was simulated with a simple abdominal model (elliptic cylinder with ∅ = 20/40 cm, length 50 cm, σ = 0.4 S/m, ε_r = 80 using "Concept II", Technical University Hamburg-Harburg, Germany). Second, an octagonal coil (∅ = 20/40 cm, Fig. 1a, [6]) was simulated with a realistic patient model ("Ella" [7] using "XFDTD MicroCluster", Remcom Inc., USA, Fig. 1b). In both scenarios, the coil was shifted 10 cm off-center to the right, was located 3 cm from the surface of the model, and was angulated to a tangential position. The resulting local SAR was calculated using the three approaches for B_z as presented above and compared with the "true" SAR resulting from the electric fields provided by the simulation software tools. Additionally, the impact of different coil positions and transverse / longitudinal angulations on BBS has been tested for the first simulation scenario (cylindrical abdomen model).

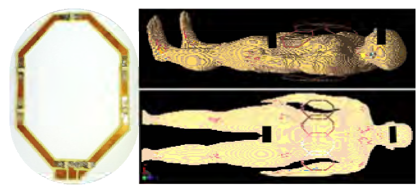

Fig. 1: Input for realistic simulation scenario: TX array element [6] (left) and patient model "Ella" [7] (right).

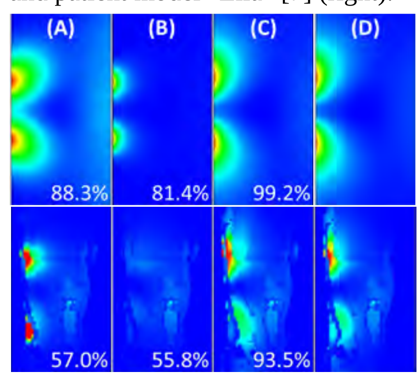

Fig. 2: Sagittal SAR distributions of (upper row) cylindrical and (lower row) realistic patient model for column (A): neglecting B_z, column (B): B_z of "empty" coil without patient, and column (C): B_z derived via Gauss's Law, Eq. (2). Correlation with expected SAR in column (D) is given at the bottom of each plot.

Results/Discussion: Results for the two investigated scenarios are given in Fig. 2. The figure shows the sagittal slice through the center of the loop coil, where maximum B_z (and thus, maximum SAR error) occurs. The assumption (A) $B_z = 0$ yields an overestimation of local SAR. This counter-intuitive result is based on opposite signs of the involved derivatives of longitudinal and transverse B_1 components. Using the B_z of an empty coil (B) yields an underestimation of local SAR. The best results are obtained using Gauss's Law for B_z determination (C). These findings agree in the two simulation scenarios, confirming their validity. - Numerous simulations varying position and angulation of the coil revealed a minor impact of these parameters on the resulting SAR error, much less than the impact of estimating B_z.

Conclusion: This study demonstrates the applicability of BBS for local surface coils via a fast and simple estimation of the unknown B_z. Thus, BBS could play an important role for RF safety of individually placed surface TX arrays, where model-based SAR estimation is hampered by the large number of degrees of freedom. Future studies have to clarify the applicability of the method for *in vivo* measurements.

References: [1] Katscher U et al., IEEE Trans Med Imag 28 (2009) 1365 [2] Voigt T et al., MRM 68 (2012) 1117 [3] Zhang X et al., IEEE Trans Med Imag 32 (2013) 1058 [4] Wang J et al., MRM 53 (2005) 408 [5] Sodickson D et al., ISMRM 20 (2012) 387 [6] Leussler C et al., ISMRM 23 (2015), subm. [7] Christ A et al., Phys Med Biol 55 (2010) N23