Local SAR reduction based on channel-dependent Tikhonov parameters

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Introduction: The possibility of high local SAR values can be a limiting factor to in-vivo transmit-SENSE applications at high field [1,2]. In this work we introduce a novel method to reduce the local SAR and demonstrate its application based on simulations.

Methods: This study relies solely on simulations of a transmit-array head coil at 7T**.** The coil consisted of 8 stripline dipoles distributed every 40-degrees on a cylindrical surface of 27.6-cm diameter, leaving an open space in front of the patient's eyes. An eight-anatomical structure human head model (provided by Aarkid, East Lothian, Scotland) was placed at the centre of the coil. The same head model with a slightly off-centered position was also considered (10°-rotation around the x and y-axes). Full-wave simulations with the finite element method (HFSS, Ansoft, Pittsburgh, PA), which take into account tuning to 297 Mhz, matching to 50-Ohm, and mutual coupling, provided the electric and magnetic field maps. Three- and five-spoke k-space trajectories [3] were designed for flip-angle (FA) homogenization in the spatial domain [4] with the local variable exchange method [5]. A 20°-angle was targeted in a central slice of the brain using 700µs apodized sinc sub-pulses (time-bandwidth product equal to 4). For the purpose of local SAR reduction, the Tikhonov parameter originally introduced by Grissom et al. [4] was generalized in the form of a diagonal matrix, allowing coil element-dependent regularization. First an initial candidate waveform is obtained using the conventional scalar form of the Tikhonov parameter. Subsequently, coil-dependent Tikhonov parameters were iteratively optimized. During this optimization procedure, the 10-gram average SAR distribution was evaluated for the candidate waveform. Incrementing the Tikhonov parameter (+5%) associated with the coil element nearest to the spatial location of the maximum 10-gram SAR, a new candidate waveform is obtained. The procedure can then be stopped when SAR guidelines are reached or when negligible gain is perceived in local SAR-limitation with respect to FA-homogenization performance. In order to minimize computation time, the method was implemented in CUDA™ and performed on a GPU (GeForce 9600m, NVIDIA®).

Results: Applying the described method with the head well centered in the coil, reductions by over a factor of 2 in local SAR were obtained (Figure). The cost in FA inhomogeneity to achieve this was only moderate: in optimized 3- and 5-spoke pulses respectively produced, through-slice normalized root mean square errors of 6.7% and 4.5% were found, relative to 4.7% and 3.1% for the initial pulse (Figure). Calculations performed with the head model slightly off-center showed SAR reduction by over a factor of 6. Based on the performance of a 2.4GHz Intel® Core™ 2 Duo laptop including a NVIDIA® GeForce® 9600m graphics card, pulses optimized over 200 iterations can be found in less than 2min.

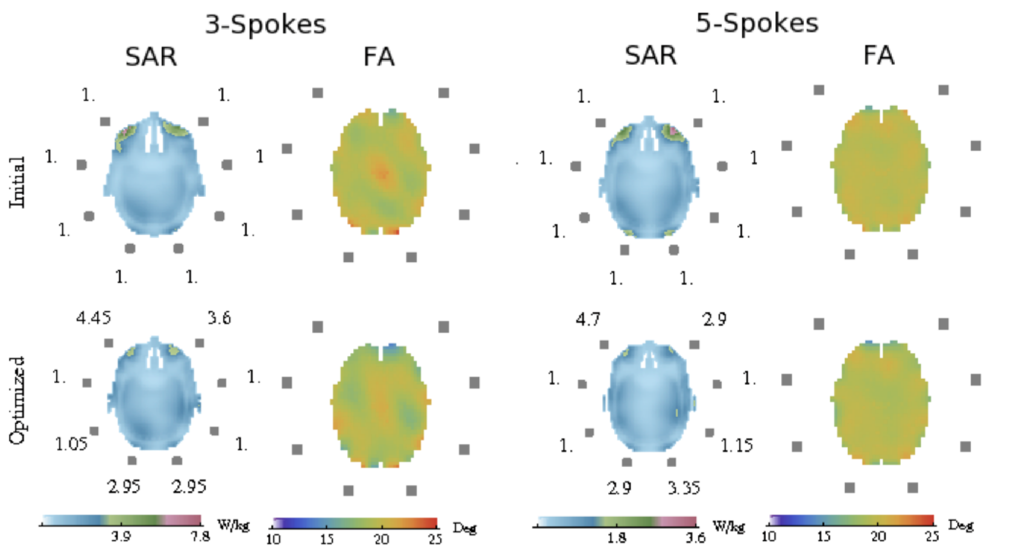

Figure: Maximum 10-gram local SAR (100% duty cycle) and flip angle (FA) distributions found for a central axial slice selective excitation pulse with a homogeneous excitation profile. SAR distributions for excitation pulses designed using respectively 3, and 5-spoke k-space trajectories are shown. The top row shows the 10-gram local SAR and FA distributions for the initial "non SAR-optimized" excitation pulses. The bottom row shows the 10-gram local SAR and FA distributions for the optimized excitation pulses. Initial and optimized coil-element-dependent Tikhonov parameters are shown (to be multiplied by 10^{-2}) next to their associated coil elements. Coil element positions are indicated by the gray squares. Also note that the maximum local SAR axial slice is generally not identical to the FA-homogenized brain central slice.

Discussion: The above results show that coil-element-dependent Tikhonov parameters can be used to reduce hot spots. This relies on the fact that the coil element closest to the maximum 10-gram local SAR is the dominant contributor. While this is true for our particular coil model, it may not apply to all coils. Observed additional improvements when considering off-centred head positions are possibly related to the scalar form used to find initial pulse candidates. The scalar form equally penalizes all coil-elements, while interaction between head and coil-element may be vastly different. In the demonstrated optimization procedure, the parameters were incremented equally for all spokes, based on the spatial position of the maximum 10-gram SAR. Other possible extensions to this method include temporal optimization considering the individual sub-pulses, and optimization to meet hardware power-limitation constraints. In the absence of patient-specific SAR information, the method could be applied to a plethora of pre-calculated simulations for pulse optimization within the limits of a specialized SAR monitor [6].

Conclusions: A novel method was demonstrated to reduce the local SAR for application with transmit SENSE. Global patient-specific local SAR mitigation is possible by introducing coil-element-dependent regularization parameters, while using standard convex optimization tools. Under the assumption that the coil element closest to the maximum 10-gram local SAR is the dominant contributor, the local SAR could be reduced by up to a factor of 6 for a variety of spoke k-space trajectories.

References:

[1] Katscher U., et al., MRM 49:144-150 (2002)
[2] Collins CM, et al., ISMRM 15:1092 (2007)
[3] Saekho S., et al., MRM 55:719-724 (2006)
[4] Grissom W., et al., MRM 56:620-629 (2006)
[7] Setsompop K., et al., MRM 59:908-915 (2008)
[6] Graesslin I, et al., ISMRM 17:302 (2009)