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.

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: