Simulation Study of Parallel Transmit Arrays for 3T Body Imaging under Local and Global SAR Constraints

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Introduction: Despite intense research in pTx hardware development there has been little theoretical optimization of pTx coil arrays, for example determining the benefit of increasing number of transmit channels [1]-[3]. Comparison of array designs is application specific and should explore how different pulse design metrics vary as the number of channels increases. In this work, we quantify the performance of three pTx body arrays with 4, 8 and 16 channels using a co-simulation strategy [1] and a pulse design algorithm incorporating simultaneous global and local SAR as well as average and maximum forward input power constraints*. We analyze RF shimming and 2 spokes excitations in the torso at 3T and compare the tradeoff between excitation fidelity, pulse power and local and global SAR.

Methods: The three whole body pTx arrays simulated (Fig. 1) were based on a cylindrical geometry (radius=35.7cm, length=35cm and 37.2cm shield radius). A co-simulation strategy [1] was employed using FEM software HFSS (Ansys, Canonsburg PA) together with the ADS circuit simulator (Agilent, Santa Clara CA) allowing simulation of coupled arrays in a realistic body model (1mm resolution, 33 tissue type, Ansys model with the liver placed at the coil isocenter) in a reasonable time (~12 hours). All loops were simulated together in order to model coupling. Lumped elements and sources were not modeled in HFSS but were replaced by 50Ω ports. The output of each HFSS simulation was the S-matrix of the system coil+patient+shield at the Larmor frequency and the electric and magnetic fields created by every port. To visualize tuning curves, the S-matrix was extrapolated to a range of frequencies by assuming that the reactance of the system coil+patient+shield had a purely inductive behavior [4]. Tuning (123.2MHz)/matching (-30dB)/decoupling (-18dB and -12dB for nearest and next-nearest neighbors, respectively) was performed by optimizing capacitor values using the gradient optimization routine of ADS. The power in each port was then used to scale their respective fields and finally obtain the $\mathbf{E}$ and $\mathbf{H}$ fields of each loop. B1+ maps [5] and SAR matrices [6] were computed from these fields. SAR matrices were compressed to a smaller set of Virtual Observation Points allowing fast computational optimization of local SAR at all positions in the body during the pulse design [7]. Least square RF shimming and 2 spokes pulses were designed for a uniform 10˚ flip angle target excitation for a transverse slice at z=0cm and z=+9cm using an interior point constrained optimization algorithm with explicit global/local SAR and maximum power constraints (15kW max. forward power). The trade-offs between excitation fidelity (RMS error wrt the target pattern), and power and SAR metrics were analyzed by plotting L-curves obtained by varying these constraints.

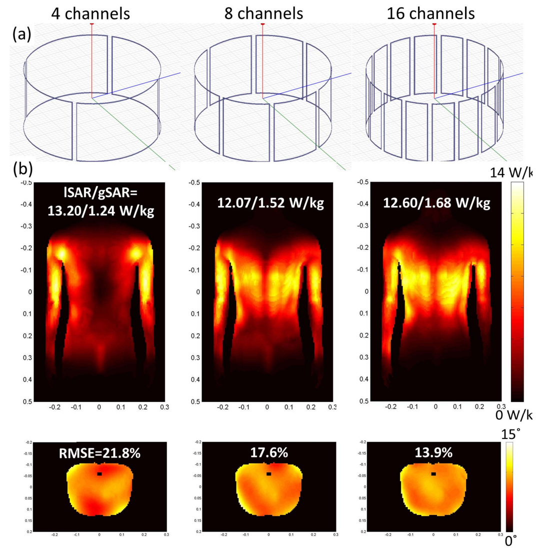

Fig. 1. (a): Snapshots of the three pTx arrays simulated in HFSS. (b): SAR and flip angle maps showing reduction of excitation error at constant local SAR with increasing number of channels.

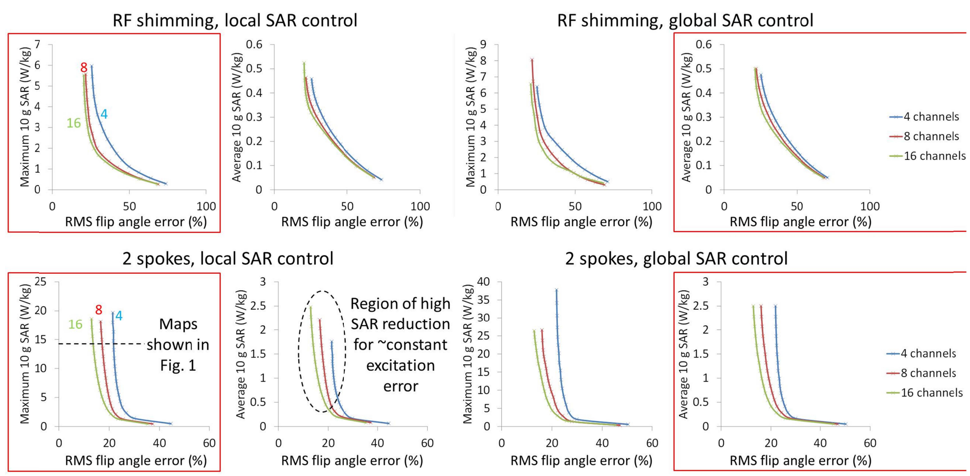

Fig. 2. L-curves showing the quantitative tradeoffs between local/global SAR and excitation error for RF shimming and 2 spokes pulses at isocenter (z=0cm). Red boxes indicate L-curves for which the y axis corresponds to the quantity being explicitly constrained.

Results: Fig. 2 shows L-curves with local and global SAR control for all designs. These show that increasing the number of channels improves the local/global SAR versus excitation error tradeoff. For RF shimming the gains in adding more than 8 channels were limited however, which is in agreement with [2]. Reductions of SAR (exc. error) for constant excitation error (SAR) with increasing number of channels were more pronounced for 2 spokes excitations (Fig. 1). In the steep regions of the 2 spokes L-curves, local SAR could be reduced, at constant excitation error, by as much as 90% when increasing the number of channels from 4 to 8 and by 50% when using 16 rather than 8 channels. We found however that this improvement was at the cost of increased forward power, which is agreement with [2]. Off-isocenter transverse excitations showed very similar trends. Another conclusion of this work is that regularization of local SAR always allows control of global SAR but that regularization of global SAR was only effective at controlling local SAR for RF shimming, not for pulses with multiple spokes.

References:

[1] Kozlov, M (2009). JMR **200**(1): 147-152.
[2] Harvey PR (2010). Proc. ISMRM **18**: 1486.
[3] Lattanzi R (2009). MRM **61**(2): 315-334.
[4] Lemdiasov, R. A. (2011). CMR A **38**(4): 133-147.
[5] Setsompop, K. (2008). MRM **60**(6): 1422-1432.
[6] Lee, J. (2011). Ph. D Dissertation, MIT.
[7] Eichfelder, G. (2011). MRM **66**(5): 1468-1476.