Z-shim RF coil design enhances parallel transmit performance in body imaging at 3T

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Introduction: There has been an increasing interest in designing RF arrays with coil elements distributed in all three dimensions so as to also allow B1+ manipulation along the Z direction. Such Z-shim coils have been shown to provide improved RF transmit efficiency for brain imaging [1,2], as compared to a conventional coil which has only in-plane encoding capability. In this study, we evaluate the performance of a Z-shim RF array designed for body imaging at 3T and compare it to a conventional array, by designing parallel transmit (pTX) RF pulses with power and SAR regularizations based on electromagnetic (EM) simulations of the two coils.

Materials and Method: The conventional coil, referred to as "1x8", consists of eight coil elements evenly arranged on a single ring with each element of 45 cm in length. The Z-shim array, defined as "2x8", is made by cutting the "1x8" array into two identical rings of eight elements each and rotating one ring about the Z axis relative to the other by half the inter element distance so as to obtain an interleaved coil distribution for reduced inter-coil coupling between the two rings (Fig. 1). Both arrays were loaded with a human whole body model (Duke, virtual family, 5mm isotropic) with the pelvis placed at the isocenter of the coil, and EM field maps were simulated for the whole body using the XFDTD software (Remcom, USA). For both arrays, one- and two-spoke pTX RF pulses were designed to achieve uniform excitation in the 3D region of interest (ROI) covering the pelvis. The pulse design was formulated as a regularized MLS problem [3], $\min_w \| |Aw| - 1 \|_2^2 + \lambda R(w)$. The regularization $R(w)$ was defined as 1) $\|w\|_2^2$ for total power control, 2) $\|S_0 w\|_2^2$ for global SAR control and 3) $\sum_{n=1}^{N_{\mathrm{VOP}}} \alpha_n \|S_n w\|_2^2$ for peak local SAR control. Here S_0 is the global SAR matrix, N_{VOP} is the number of virtual observation points (VOP) [4], S_n is the local SAR matrix derived for the *n*-th VOP, and α_n is a variable that weights the peak local SAR estimate of the *n*-th VOP. The design problem was solved in a way similar to those in [5]. In order to leave the coil design an only impacting factor on the result, the spoke placement in two-spoke design was optimized in the 3D k-space for maximized use of the degree of freedom provided by gradient modulation. L curves quantifying the tradeoff between peak 10g SAR/global SAR/total power and excitation errors (defined as the root mean square error (RMSE)) were generated for each pulse design scenario by varying λ in pulse design. SAR quantities averaged over 2 ms were calculated by exhaustive search for a 10° nominal flip angle (FA) using the same 1-ms sinc subpulse for all RF pulses. All calculations except for EM modeling were performed in Matlab (Mathworks, USA).

Results and Discussion: With the same resulting peak 10g SAR, the 2x8 array gave rise to significantly improved FA uniformities in the ROI as compared to the 1x8 counterpart (Fig. 1). Quantitatively, the FA inhomogeneity, measured by the coefficient of variation (CV, i.e., std/mean), reduced from 17% for the 1x8 array, to 8% for the 2x8 array. The improvement of FA uniformity when using the 2x8 array, however, was obtained at the cost of increased global SAR. More comprehensive comparison via L curves revealed that at constant excitation errors the 2x8 body array always outperformed the 1x8 array in reducing the quantity that had been regularized in pulse design (Fig. 2). For both coil designs, neither peak local SAR nor global SAR can be effectively controlled via total RF power constraint. Interestingly, this is in contrast with another report where, using a surface array at 7T (instead of body coil at 3 T), controlling the total RF power only appeared to consistently also control peak local SAR and global SAR [6]. In summary, we have demonstrated based on EM simulations that a Z-shim RF array can give rise to large improvement of FA homogenization and/or reduction of SAR in pTX for body imaging at 3T, as compared to a conventional coil without Z-encoding capability.

References: **1.** Adriany et al., ISMRM 2010 p3831. **2.** Wu et al., ISMRM 2012 p638. **3.** Setsompop et al., MRM 60:1422-32(2008). **4.** Eichfelder et al., MRM 66:1468-76(2011). **5.** Lee et al., MRM 67:1566-78(2012). **6.** Wu et al, ISMRM 2011 p492. **Acknowledgments:** P41 EB015894, R21 EB009133, R01 EB006835, and R01 EB007327.

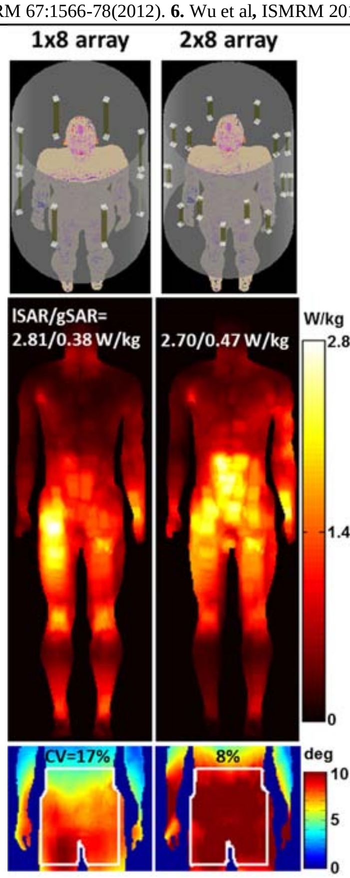

Fig. 1. RF arrays compared (top), along with MIP of 10g SAR (middle) and flip angle (FA) map with ROI marked in white (bottom). Note that FA homogenization improved drastically with the 2x8 array for the same peak 10g SAR.

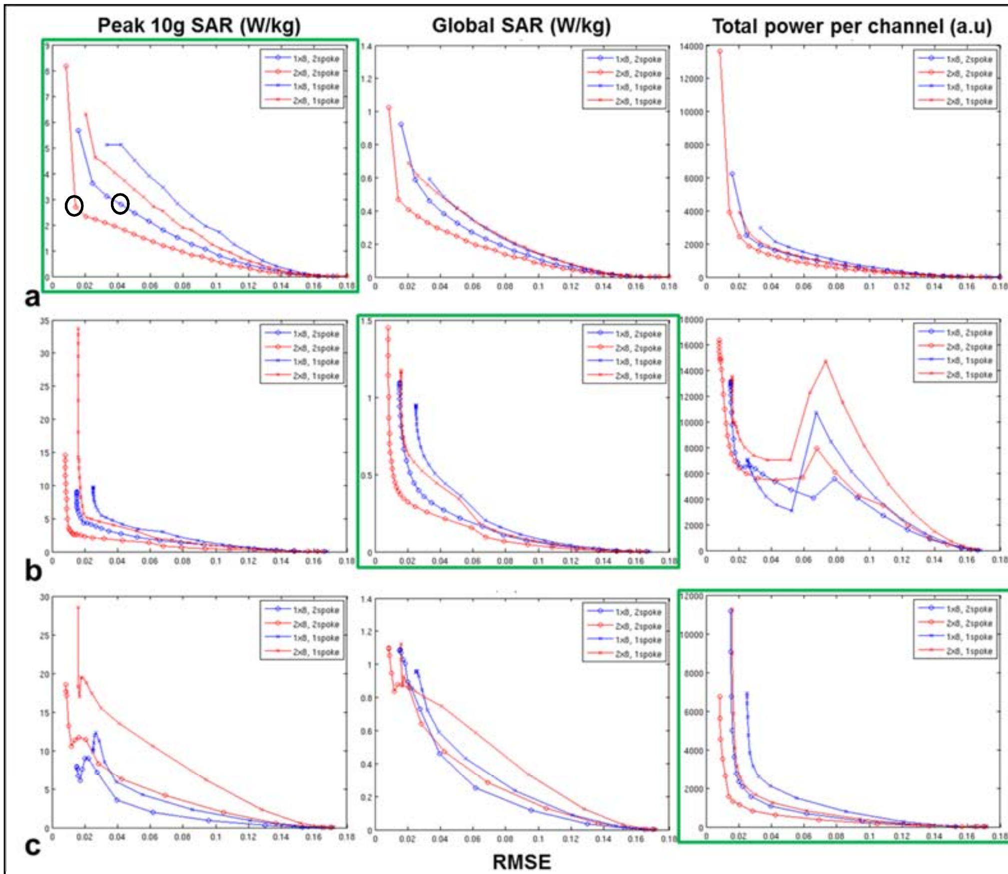

Fig. 2. L curves quantifying tradeoffs between peak 10g SAR/global SAR/total RF power and excitation error, for peak 10g SAR controlled (a), global SAR controlled (b) and total power controlled (c) pulse design using 1x8 (blue) and 2x8 (red) arrays with 1 spoke (×) and 2 spokes (○). The L curve in the green box is for the quantity that is regularized in pulse design. SAR and FA maps shown in Fig. 1 are for the two points circled in the first plot in (a).