Z-stacked RF array design enhances parallel transmit multiband RF performance in whole brain simultaneous multislice imaging at 7T

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Introduction: Simultaneous MultiSlice (SMS) MR imaging (1) using MultiBand (MB) RF pulses is becoming increasingly popular in the neuroimaging community (2-4). Recently, there has been an interest in utilizing multielement RF arrays in combination with multichannel (pTx) MB pulse design to reduce transmit B1 (B1+) inhomogeneity and SAR (5,6) for SMS/MB imaging. Meanwhile, it has been shown that the use of transmit coil elements that approximately align with the slice direction, such as Z-stacked arrays with azimuthally distributed elements in two rings displaced from each other along the Z-direction versus axial slices, can provide improved RF performance for pTx non-MB pulses at 3T (7) and 7T (8), as compared to conventional single ring arrays. In this study, we evaluate the performance of such transmit coil element/slice geometries for achieving whole brain SMS/MB imaging at 7T by designing pTx MB RF pulses based on electromagnetic (EM) simulations.

Method: Three head RF arrays were compared at 7T. The first one, referred to as “1x8”, is a conventional array comprised of eight elements evenly arranged azimuthally on a single ring. The second array, referred to as “1x16”, has the same single ring structure, but with twice as many coils elements. The third array, referred to as “2x8”, has two rings along Z (i.e. along B0) each of eight azimuthally placed elements and has a 22.5° shift between the two rings. All three arrays were loaded with a same human head and shoulder model (Duke, virtual family, 2x2x2.5mm^3) with the brain placed at the isocenter of the coil, and the respective EM field maps were simulated using the XFDTD software (Remcom, USA). For each array, we designed pTx MB pulses with MB=4 to excite axial and coronal slices and to cover the whole brain. A new *slab-wise* pTx MB pulse design (9) targeting volumetric coverage was conducted to obtain a *single* pTx MB4 pulse for which the four constituting band-specific pTx single-band (SB) pulses were calculated based on four contiguous slabs using a few B1+ slices equidistantly placed within the brain (16 and 24 slices for axial and coronal excitations, respectively). All pulses were calculated by solving a local SAR regularized MLS problem (10), $\min_w \| |Aw| - 1 \|_2^2 + \lambda \sum_{n=1}^{N_{\text{VOP}}} \alpha_n \|S_n w\|_2^2$, based on a model compression method (11). SAR quantities were calculated by exhaustive search and were obtained for whole brain SMS/MB imaging with TR=1 s, slice thickness=1 mm (corresponding to 120 axial and 144 coronal slices), nominal flip angle=10°, and pulse duration=1 ms. All calculations except for EM modeling were performed in Matlab (Mathworks, USA).

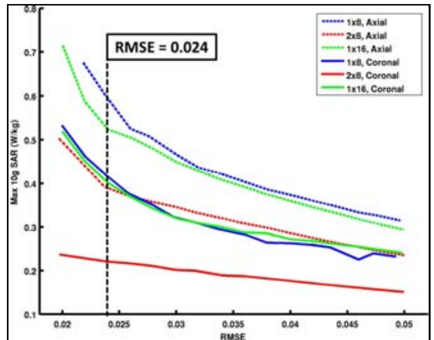

Fig. 1. L-curves quantifying the tradeoff between peak 10g SAR and root mean squared excitation error (RMSE) for slab-wise pTx MB4 pulses designed for different slice directions and using different RF arrays. All pulses were peak 10g SAR regularized based on the EM modeling of the respective arrays. Note that using the 2x8 array to excite coronal slices constantly provided best RF performance among all design scenarios over the RMSE range investigated.

Results and Discussion: For all three arrays, exciting coronal slices gave rise to lower SAR values (up to ~45% lower) than exciting axial slices when achieving the same excitation fidelity despite a larger number of coronal slices need to be excited for the same spatial resolution (Fig. 1). This is primarily due to the fact that using a coronal slice direction with the azimuthally arranged coil structure allows RF power of individual pTx SB pulses to be delivered mostly through coil elements that are near the respective target slices; this in turn resulted in localized and *most importantly non-overlapping* SAR hotspots between SB pulses, thereby yielding much reduced local SAR for the summed pTx MB pulse. Furthermore, for either slice direction, the double ring 2x8 array consistently and significantly outperformed the other two conventional single ring arrays over the RMSE range investigated (Fig. 1); this was achieved by additional degrees of freedom in RF control allowing RF power distribution between the two rings. For example, when exciting the coronal slices within the most anterior slab, the pTx SB#1 pulse was designed to transmit the majority of its RF power only via coil elements that are on the upper ring and are near the targeted brain slices, thereby yielding more localized and reduced SAR distribution (Fig. 2). Interestingly, although carrying twice as many elements, the 1x16 arrays exhibited similar, but not superior, RF performance to the 1x8 array, especially when exciting coronal slices. In conclusion, we have demonstrated based on EM simulations that the use of a Z-stacked RF array with coil elements distributed in all three spatial dimensions can drastically improve RF performance when utilizing pTx MB pulses to pursue whole brain SMS/MB imaging at 7T.

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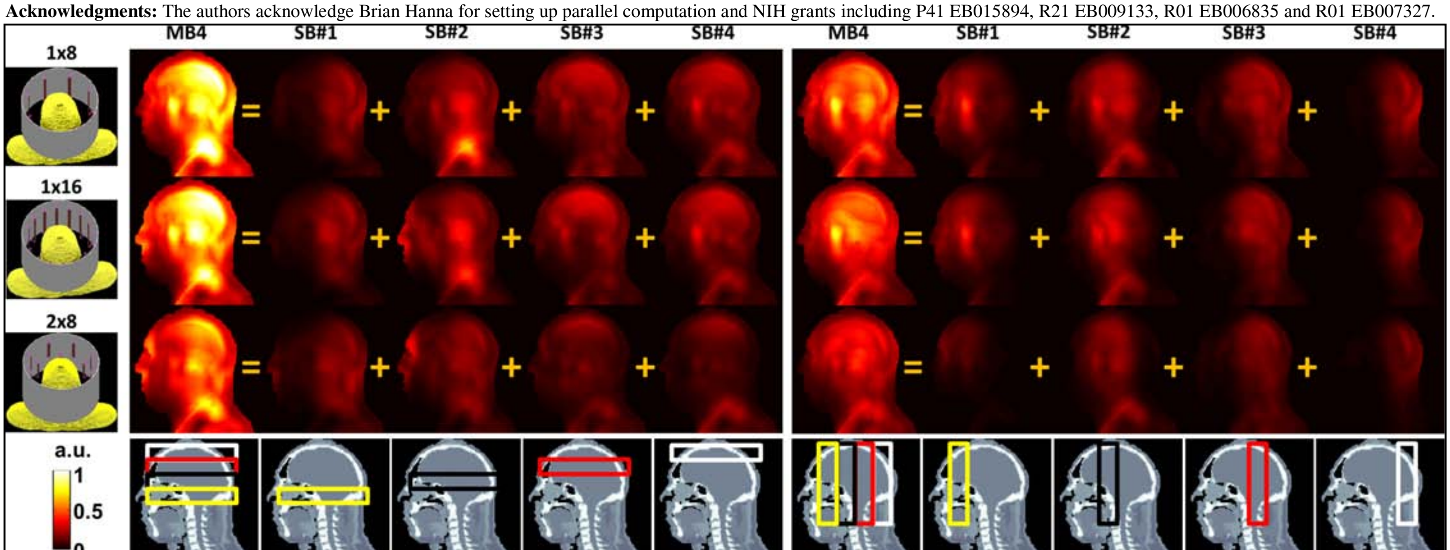

Fig. 2. Sagittal maximum intensity projections of 10g SAR for the slab-wise pTx MB4 RF pulse and its four constituting band-specific pTx SB pulses, designed to excite axial (left panel) and coronal (right panel) slices when using 1x8 (1st row), 1x16 (2nd row) and 2x8 (3rd row) RF arrays. All pTx MB pulses here were designed with peak 10g SAR control to achieve the same excitation fidelity (RMSE=0.024, as indicated in Fig. 1). Note how the use of the 2x8 array led to much reduced local SAR hotspots (~45% lower for coronal and up to ~33% lower for axial excitation) by allowing RF power to be distributed between the two rings.