Towards routine application of dynamic parallel transmission for whole-brain imaging at 9.4 Tesla

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Purpose: The short RF wavelength in ultra-high field MRI (≥ 7T) and its impact on B_1^+ uniformity and local SAR complicates the acquisition of brain images with consistent contrast. Remarkable progress has been made in parallel transmission (pTx) methodology and RF coil design, however, the requirements on a multi-purpose, pTx-enabled RF setup for whole-brain imaging are high: Transmit arrays must be well-decoupled, efficient, compatible with common eight- or sixteen channel pTx hardware and should provide sensitivities distributed in all spatial dimensions. In addition, high-SNR parallel signal reception from the entire brain is desired. For *in vivo* experiments, comprehensive numerical simulations must ensure compliance with SAR limits. Finally, rapid volumetric calibration scans (B_1^+ and B_0 maps) constitute the basis for subject-specific pTx pulse design.
In this work, we report our progress towards a multi-purpose RF setup and the corresponding workflow for routine pTx in the brain at 9.4 T.

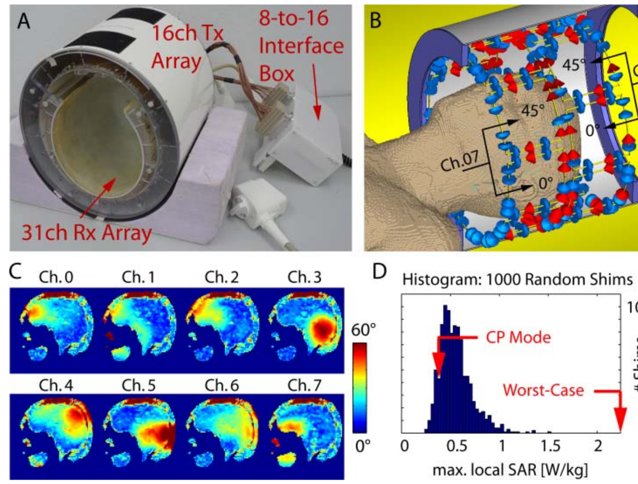

Figure 1: A: RF coil setup. B: Numerical model of the dual-row transmit array. C: Single-channel 3D flip angle maps acquired using a 3D DREAM sequence. D: Histogram of maximum local SAR in 1000 randomly chosen RF shims (input power = 1W for each shim).

Methods: An RF setup consisting of a 16-ch dual-row transmit array and a 31-ch receive array [1] was interfaced to an eight-channel pTx system (Siemens Tx Array Step 2) using a home-built 8-to-16 channel interface device (Fig. 1A) [2].Two adjacent elements in a single row were hard-wired with a 45° phase difference, effectively creating an 8-ch dual-row array with four elements in each row. For online local SAR supervision, the electric fields produced by the "combined" elements were simulated [3] in the Virtual Family's "Duke" model using CST Studio Suite (Fig. 1B). Local SAR matrices (Q-matrices [4]) were created for each voxel in the Duke model using MATLAB and were reduced to a few hundred Virtual Observation Points (VOPs) [5] for usage in the scanner software. A safety factor of two was applied to all SAR-related results. Local SAR characteristics were assessed from the Q-matrices by calculating the maximum SAR across the model for 1000 randomly chosen RF shims. Whole-brain, single-channel complex B_1^+ maps and a B_0 map were acquired using a 3D implementation of DREAM [6] (TR/TR_{SHOT} = 4.1/5000 ms, 5 shots, TE_{STE}/TE_{FID} = 1.62/2.28 ms, resolution = 4x3x3 mm³, AT = 4 min). For demonstration of whole-brain coverage, Spokes pulses [7] that aimed for a homogeneous flip angle (FA) in a coronal slice were calculated *in situ* using MATLAB and inserted into a vendor-provided 2D GRE sequence with TR/TE = 250/9 ms, resolution = 0.7x0.7x1.5 mm³, BW = 400 Hz/pixel, AT = 1:20 min. An identical scan in CP mode was performed for comparison.

Results: An analysis of the random RF shims predicts local SAR values between 0.23 W/kg and 2.24 W/kg for an input power of 1W at the coil input. The worst-case SAR was obtained from an eigenvalue analysis [4]. The spread in local SAR resembles a gamma-distribution (Fig. 1D) with most RF shims resulting in values around the median of 0.53 W/kg (including CP mode with 0.38 W/kg) and only few shims causing local SAR significantly above 1 W/kg. Whole-brain complex, single-channel B_1^+ maps (Fig. 1C) and a B_0 map could be acquired within 4 minutes using DREAM. The Spokes pulse (four sub-pulses, pulse duration = 5.9 ms) provided marked improvement in image homogeneity (Fig. 2, left) in a coronal slice with large field-of-view and restored signal in regions where dropouts occurred in CP mode, e.g. the lower temporal lobes and the brainstem. The difference between the two images resembles the FA distribution in CP mode (Fig.2) and demonstrates successful FA homogenization achieved by the Spokes method.

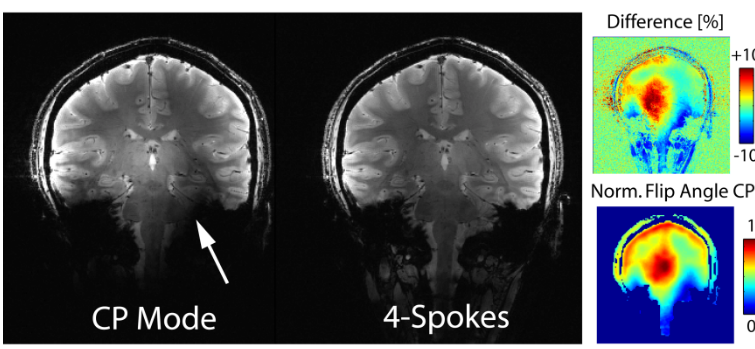

Figure 2: Coronal 2D GRE images using CP Mode (left) and a 4-Spokes excitation. The difference in signal intensity between both images (top right) resembles the FA inhomogeneity in CP mode (bottom right).

Discussion: The combination of a dual-row transmit array and a multichannel receive array provides RF management in all spatial dimensions together with high-SNR signal reception from the entire brain; constituting a multi-purpose setup for pTx in the human brain at 9.4 Tesla. The DREAM sequence allows for volumetric RF calibration scans, essential for 3D pulses such as kT-points [8], within timescales acceptable for *in vivo* measurements. Future work includes optimization of calibration scan parameters and of the pulse design workflow.

References: [1] Shajan et al. MRM 2014; 71:870–879. [2] Shajan et al ISMRM 2015. [3] Hoffmann et al. MAGMA 2014; 27:373–386. [4] Homann et al. MAGMA 2012; 25(3):193-204. [5] Eichfelder et al. MRM 2011; 66(5):1468-1476. [6] Nehrke et al. MRM 2012; 68:1517–1526. [7] Setsompop et al. MRM 2008; 60(6):1422-1432. [8] Cloos et al. MRM 2012; 67(1):72-80.