Whole brain single shot diffusion weighted EPI at 7 Tesla using parallel transmit multislice multiband RF pulses

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Introduction: Simultaneous Multi-Slice (SMS) imaging [1] using MultiBand (MB) RF pulses has shown great success in functional and diffusion weighted (DW) MRI studies of the brain [2-5]. Recently, this technique has been combined with parallel transmission (pTx) and it has been demonstrated that pTx MB pulse design [6] can significantly improve transmit B1 (B1+) homogeneity at 7T and/or reduce RF power consumption relative to a single channel Circular Polarized (CP) mode application. Those results were obtained for a few slices in the brain using a gradient echo imaging sequence and did not tackle the problem of whole brain coverage or more challenging spin-echo based acquisitions. In the present study, advances towards volumetric coverage with pTx MB pulses is reported and results of *whole brain* single-shot, diffusion weighted echo planar imaging (DW-EPI) at 7T using pTx MB RF pulses are presented.

Methods: Experiments were conducted at 7T equipped with a 16-channel prototype pTx system (Siemens, Erlangen, Germany). A number of healthy volunteers who signed a consent form were scanned and representative results are shown. A head array with 16 azimuthally distributed elements, similar to [7], was employed for both RF transmission and reception. To capitalize on the coil geometry, *coronal* slices were imaged. For practical scan session times, we employed a new *slab-wise* pulse design [8] where four contiguous slabs jointly covering the brain volume in coronal views were prescribed to design a single 1-spoke pTx MB4 pulse; the *band-specific* phase and gain of the four pTx single band (SB) pulses were calculated from B1+ maps [9] estimated only from 11 slices that were equidistantly distributed over the four slabs (Fig. 1). The target was uniform B1+ within brain tissues that were defined from manually drawn regions of interest on the B1+ maps. The RF shim sets for individual pTx SB pulses were obtained via magnitude least squares optimization [10] and based on L-curve criteria. To acquire whole brain single-shot DW-EPI datasets, a new pulse sequence utilizing pTx MB pulses was developed based on the SMS/MB imaging sequence that is currently being used in the WashU consortium of the Human Connectome Project (HCP, http://humanconnectome.org). The same RF shim set was utilized for both excitation and refocusing. The DW images were further analyzed to derive diffusion tensor images (DTI) following the HCP data processing pipeline [11]. For comparison, a 3D B1 phase shimming targeting a CP-like mode B1+ distribution [12] was also performed to mimic single channel transmission and was used to assemble so called "CP mode MB pulses" for data acquisition. For all acquisitions, RF voltages were adjusted to achieve the nominal flip angles (i.e., 90° for excitation and 180° for refocusing) at the maximum flip angle across the whole brain. All pulse calculations were performed in Matlab (Mathworks, USA).

Results and Discussion: Using pTx MB pulses gave rise to drastically improved B1+ homogeneity across the brain as compared to the CP mode counterpart. The std/mean of B1+ variations decreased from ~27% for CP mode to ~12% for pTx, concurrently with a ~40% reduction in total RF power. Correspondingly, the traditional image signal dropout seen in the lower brain when using CP mode MB pulses to acquire DW images was effectively recovered by using the pTx MB pulses (Fig. 2). As a result, significantly enhanced depiction of the fiber orientation was achieved with pTx MB, especially in the cerebellum and midbrain regions. Additionally, calculations of RF power deposition in tissues (i.e. SAR) based on electromagnetic modeling revealed that although not explicitly constrained in pulse design, peak 10g SAR was reduced by 21% when using pTx MB pulses. This was mostly due to the fact that each pTx SB pulse tends to deliver the majority of its RF power (>70%) via the coil elements that are near the target slices, yielding *localized* and *non-overlapping* SAR hot spots between different bands. As a result, these SB hot spots do not add up during the application of the summed MB pulse, thereby leading to a reduced local SAR. In conclusion, we have successfully demonstrated the utility of pTx technology for SMS/MB imaging when pursuing whole brain DW-EPI at 7T. Critical to this accomplishment is an efficient and practical slab-wise pTx MB RF pulse design which bases the pulse calculation on a few contiguous slabs covering the entire volume of interest rather than on the many individual imaging slices to be obtained in the data acquisition. Future work includes the investigation of the potential benefit of designing multiple slab-wise pTx MB pulses and using a Z-stacked RF array for whole brain pTx SMS/MB imaging.

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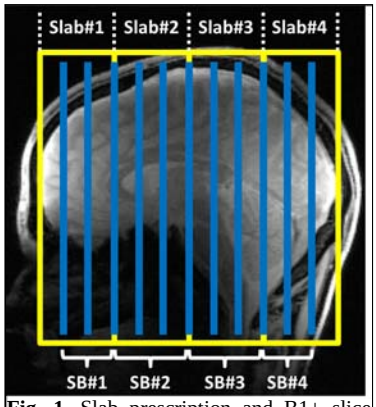

Fig. 1. Slab prescription and B1+ slice placement for a single slab-wise pTx MB4 pulse design. Note that although designed only with a few B1+ slices, the pTx SB pulses will be used to excite every imaging slice within the respective slabs during data acquisition.

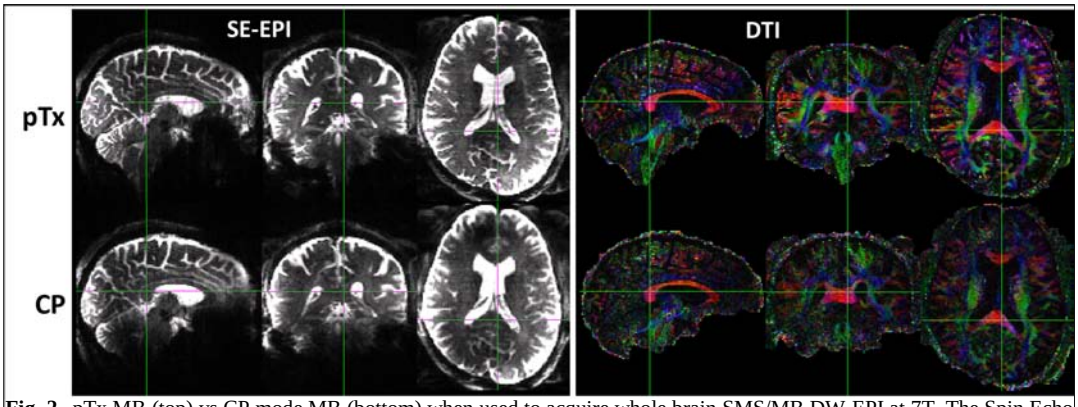

Fig. 2. pTx MB (top) vs CP mode MB (bottom) when used to acquire whole brain SMS/MB DW-EPI at 7T. The Spin Echo EPI corresponding to b-value = 0 is shown on the left and the derived RGB-colored fiber orientation map on the right. The DW-EPI datasets were acquired with 1.5 mm isotropic resolution, b-value = 1200 s/mm^2, 30 diffusion directions, MB = 4, PEshift = FOV/3, iPAT = 2, partial Fourier = 7/8, matrix size = 170×114, 124 slices, and TR/TE = 6000/64 ms. For distortion correction, each image volume was acquired twice with left-right and right-left phase encodes. Note that the use of pTx MB pulses resulted in significantly improved B1+ homogeneity across the whole brain, thereby yielding largely enhanced depiction of fiber orientation especially in the cerebellum and midbrain, as compared to the CP mode counterpart.