# Slab-selective pTX Multiband TOF Angiography at 7 Tesla

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**INTRODUCTION**. Time-of-flight (TOF) angiography significantly benefits from ultra-high field (UHF; ≥7 Tesla) allowing for improved contrast between blood vessel and static tissue and higher spatial resolution [1,2]. However, this push towards high-resolution TOF at UHF is associated with challenges: prolonged acquisition and spatially heterogeneous contrast due to RF field inhomogeneity [2]. Previously, we have addressed the spatial heterogeneity by utilizing a 16-channel parallel transmit (pTX) system together with single and multi-spoke RF pulses [3]. In this work we aim to simultaneously address both challenges, by applying a pTX multi-band (MB) technique to reduce the acquisition time [4] while achieving homogeneous excitation.

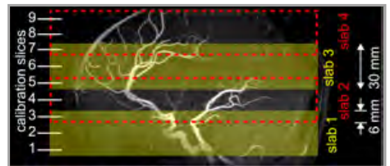


***Fig.1:*** *Positioning of the 4 overlapping TOF slabs and location of the 9 B1+ calibration slices. Slabs 1+3 as well as slabs 2+4 were excited simultaneously.*

**METHODS.** Three healthy volunteers were imaged after signing consent. All experiments were performed on a 7T scanner equipped with a 16-channel pTX prototype console (Siemens, Erlangen). A 16-channel head array was used for both RF transmission and reception [5]. TOF images of the whole brain were acquired from four, 30-mm thick imaging slabs with 6-mm oversampling and with adjacent slabs overlapping by 6 mm (Fig.1). Two separate slabs were excited and acquired simultaneously: first slabs 1+3 and then slabs 2+4. A fast B1+ estimation technique [6] was employed to acquire multichannel B1+ maps from 9 equidistant slices across the whole brain, giving 3 B1+ mapping slices per slab with slices 3, 5 and 7 shared by 2 neighboring slabs (Fig.1). A slab selective pTX MB pulse design algorithm proposed by Wu et al. [7,8] was used to optimize B1+ homogeneity individually for each slab with total RF power minimization using a single spoke. A 2-ms asymmetric RF pulse from vendor's TOF sequence was utilized to assemble the 16 final MB RF waveforms. Note that the realization of such multichannel MB RF pulses requires a pTX system [7]. MB and single band (SB) TOF images were acquired with following parameters: FOV=240x165x102mm$^3$, TE/TR=3.1/20ms, flip angle (FA)=20°, resolution=0.75mm isotropic. No in-plane Grappa or partial Fourier was applied. CAIPIRINHA [9] was applied to the RF pulses to shift the upper slab by FOV/2. Separation of the 3D slabs was performed on a slice-by-slice basis using a slice Grappa reconstruction algorithm [10,11]. The Grappa kernel was calibrated using either: i) the SB TOF dataset or ii) another low resolution (0.75x1.5x1.5mm3) dataset acquired with matched parameters but using TR=7ms and FA=5° which reduced the acquisition time of the calibration dataset to 1:28min. To evaluate reductions of the arterial signal within the upper slab due to blood being partially saturated when traversing the lower slab, three excitation schemes were employed while acquiring a full *imaging* FOV of 102mm: i) excitation of slab 3 only, ii) excitation of slab 1 and 3 simultaneously and iii) a single slab exciting the entire FOV. Signal intensities within three arteries of different vessel sizes were analyzed in slab 3.

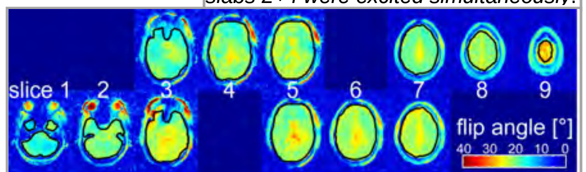


***Fig.2:*** *Bloch simulations of applied slab selective pTX MB pulses calculated based on 3 slices per slab.*

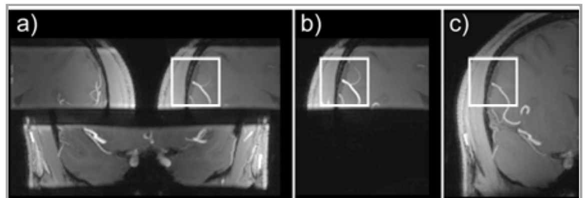


***Fig.3:*** *Excitation of (a) slabs 1+3 with Caipirinha applied, (b) slab 3 only and (c) full brain excitation. Imaging FOV covered the entire brain in all 3 cases.*

**RESULTS/DISCUSSION.** Two-fold speedup was achieved by using MB acquisition (7:50 vs 15:40 min for SB acquisition). Overall FA heterogeneity for MB excitation was 13.6% as measured by std/mean of the FA based on Bloch simulations (Fig.2), which could be further improved by utilizing 2-spoke pulses [3]. As a result of simultaneous excitation of a lower slab, the arterial signal in the upper slab is reduced to 63-80% as compared to the SB excitation (Fig.3); however the signal was still higher than that of exciting the entire brain. Comparable image quality was seen in Fig.4 in the unaliased MB images as compared to SB acquisition (here the high resolution dataset was used for calibration). Homogeneous contrast can be appreciated in the background signal confirming the homogeneous FA as predicted by Bloch simulations. No difference in unaliased image quality could be observed when using the low resolution calibration data for MB reconstruction compared to high resolution calibration dataset but the total acquisition time (calibration + acquisition) was reduced by 41% compared to SB. Maximum leakage signal was 3 times of the mean noise level. Some leakage was likely to result from flow artifacts that could be reduced using flow compensation (not applied in this study). Final maximum intensity projection (MIP) images presented clean MB separation with overall strong and homogeneous contrast (Fig. 5). Preliminary simulations show that using more and thinner slabs can reduce the signal loss observed in vessels of the superior slabs. Another approach to reduce this effect consists in adjusting the flip angle individually for each slab following the idea of TONE pulses [12]. Lower venous signals can be observed in the MIP images obtained from MB TOF acquisition (arrow in Fig.5), a favorable side-effect that may reduce the need for venous saturation pulses used in clinical routine.

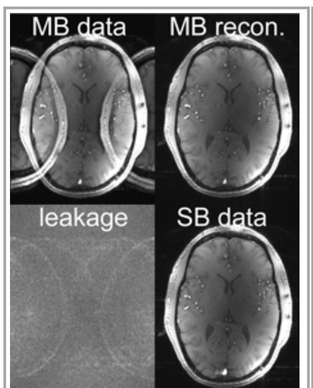


***Fig.4:*** *Axial TOF images of a slice in slab 2: aliased (a) and reconstructed (b) MB images; signal leakage from a slice in slab 4 (c) and SB data (d).*

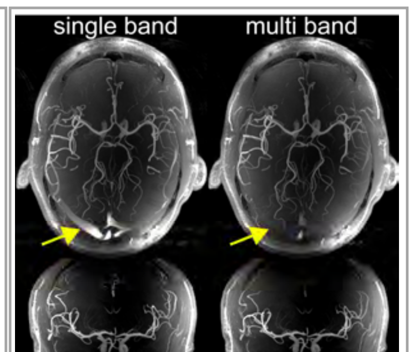


***Fig.5:*** *Axial 40mm and coronal 30mm Maximum intensity projections of SB and reconstructed MB TOF data. Images are not corrected for receive profiles. Arrow indicates venous blood signal suppression in sagittal sinus due to multiband excitation.*

**CONCLUSION.** We have demonstrated the feasibility and usefulness of slab selective pTx MB RF pulses to reduce acquisition time and contrast inhomogeneity for TOF imaging at 7T. Such pTx MB RF pulses are expected to play an important role to push further clinical applications of 7T TOF imaging.

**ACKNOWLEDGMENTS**: P41 EB015894, S10 RR026783, KECK Foundation. **REFERENCES** [1] von Morze, JMRI 26:900 [2] Schmitter, MRM 70:1210 [3] Schmitter, Invest. Radiol. In press. [4] Schultz, ISMRM 2014:1505 [5] Adriany, MRM 59:590 [6] Van de Moortele , ISMRM 2009:367 [7] Wu, MRM 70:630 [8] Wu, ISMRM 2014:4333, [9] Breuer, MRM 53:684 [10] Moeller, MRM 63:1144 [11] Setsompop, MRM 67:1210 [12] Atkinson Radiology 190:890