Functional ASL at 9.4 T – a comparison between balanced SSFP and GRE-EPI readout

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Purpose: Functional arterial spin labeling (fASL) has a higher specificity and long term reproducibility than BOLD fMRI but suffers from low temporal and spatial resolution. These disadvantages are reduced when at higher field strength where ASL benefits from the increased intrinsic SNR and from the prolongation of longitudinal relaxation times. However, stronger static and transmit field inhomogeneities and increased SAR makes the ASL preparation and signal readout challenging. One of the main difficulties in the implementation of fASL are image distortions and BOLD contamination when a GRE-EPI readout is used. The latter issue was addressed by several studies performed at 7T during the last years [1, 2].
To investigate the feasibility of functional ASL studies at an even higher field strength of 9.4 T, two FAIR experiments were performed. The first one used a GRE-EPI readout, with the shortest possible echo time, and the second one a balanced SSFP (bSSFP) readout to achieve a minimum of BOLD contamination and image distortions.

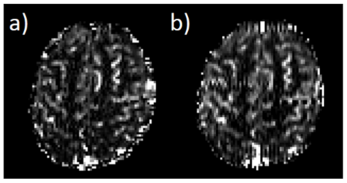

Figure 1: Mean perfusion weighted image of the central slice acquired with GRE-EPI (a) and bSSFP (b).

Methods: In both ASL experiments, an adiabatic time resampled FOCI (TR-FOCI) pulse was used for the FAIR preparation. The pulse was optimized with a genetic algorithm proposed by Hurley et al.[3] but with modified constraints in order to match the capabilities of our system.
A single healthy subject (male, 33yo.) was measured on a Siemens Magnetom 9.4 T scanner with a home-built 16 channel transmit array combined with a 31 channel receive helmet [4]. During the fASL experiment, the subject was asked to perform a bilateral finger-tapping task (thumb to pinkie and backwards) for 45 s and then rest for the following 45 s. In total 83 tag-control pairs were acquired with a sequence TR of 4.5 s, 2x2x2.5 mm³ resolution and a TI of 1700 ms (for the central slice of the acquired 7 slices). FAIR GRE-EPI parameters: TE = 12 ms, FA = 56°, GRAPPA 3, 6/8 partial Fourier. FAIR bSSFP parameters: TR 4 ms, FA = 7°, GRAPPA 2, 6/8 partial Fourier. The flip angle of both sequences was limited by the SAR supervision of the scanner. In addition to the fASL measurements, a MP2RAGE[5] with a voxelsize of 1x1x1 mm³ was acquired for anatomical co-registration and an actual-flip angle map for the calculation of the true achieved flip angle.
Image reconstruction and preprocessing was performed offline in Matlab (MathWorks, USA). The first five pairs of the fASL datasets were neglected in the evaluation. For the GRE-EPI readout, a surround subtraction scheme was applied to reduce the contamination of fASL signal with BOLD [6]. Activation maps were obtained using the FEAT algorithm of FSL (FMRIB, Oxford, UK) and registered to the MP2RAGE with FLIRT.

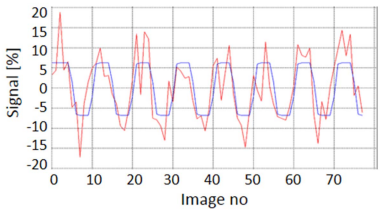

Figure 2: Signal time course of the voxel with the highest z-score in the balanced SSFP dataset. Red: voxel intensity. Blue: paradigm.

Results: Based on the acquired B_1^+ map the actual flip angle of the bSSFP readout was calculated as 5 ° and for the GRE-EPI 40 °. Figure 1 shows the mean perfusion weighted image of the central slice for both experiments. The perfusion time course of the signal with the highest z-score is plotted in Figure 2. One can clearly see the perfusion increase evoked by the stimulus. Figure 3 shows the activation maps registered on the anatomical reference volume. Both sequences clearly show an event related perfusion change in the motor cortex. However, the fASL sequence with the balanced SSFP readout shows higher z-scores and more activated voxels than the FAIR GRE-EPI.

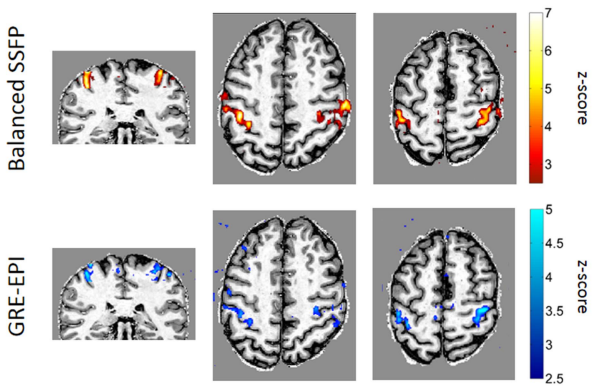

Figure 3: Functional ASL activation maps co-registered to an anatomical MP2RAGE. The balanced SSFP perfusion maps showed stronger correlation with the finger-tapping paradigm than the perfusion maps obtained from the GRE-EPI. Note the different scaling of the z-cores.

Discussion & Conclusion: To our knowledge, this work shows the first time that high resolution functional ASL can be performed at an ultra-high field strength of 9.4 T. Although the flip angle of both acquisition schemes was limited due to SAR restrictions, we were able to obtain activation maps clearly showing event related perfusion changes in the motor cortex. Interestingly no significant signal change was found in the supplementary motor area. This might be due to the lower flip angle in the central part of the brain.
The measured bSSFP doesn´t show any distortions but can suffer from banding artifacts in areas with strong susceptibility gradients and has a longer acquisition time per slice. Furthermore, the ASL signal is attenuated during the balanced SSFP readout since both, the tag and the control condition, will finally reach the same steady state [7]. To obtain the maximum perfusion contrast one can use centric reordered k-space sampling. Another possibility is to sample the k-space only partially to shift the k-space center close to the beginning of the readout train.
Functional ASL images acquired with gradient echo EPI can be contaminated with BOLD related signal changes and distorted by static field inhomogeneities. The influence of T_2^* variations can be reduced when the surround subtraction method is used to calculate the perfusion weighted images. However, this correction method might fail for long sequence TRs and requires further study.

References: 1. Zuo et al., PLOSONE 8(6): e66612; 2. Grossman et al., Proc. Intl. Soc. Mag. Reson. Med. 16 (2008); 3. Hurley et al., MRM 63:51-58 (2010); 4. Shajan et al., DOI 10.1002/mrm.24276; 5. Marques at al., Neuroimage 49: 1271-1281 (2010); 6. Lu et al., MRM 56:546-552 (2006); 7. Martirosian et al., MRM 51:353-361 (2004)