COMPARISON OF 3 AND 7 TESLA ARTERIAL SPIN LABELLING TECHNIQUES FOR SIMULTANEOUS FUNCTIONAL PERFUSION AND BOLD MRI STUDIES

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Introduction: Arterial spin labelling (ASL) has recently gained wide acceptance as the technique of choice for non-invasive cerebral perfusion (CBF) measurements in health and disease [1]. However, ASL can also offer improved understanding of the changes in brain physiology during neural activity, due to its ability to simultaneously acquire CBF and BOLD data [2, 3]. The sequence requirements in this case are slightly different than for the studies focusing solely on perfusion. In particular, background suppression, typically used in the latter case, compromises BOLD despite improving CBF sensitivity [4]. Moreover, 2D single-shot approaches offer better temporal resolution due to shorter effective repetition time (TR) in contrast to 3D segmented acquisitions, commonly used in baseline perfusion imaging. The pseudo-continuous ASL (pCASL) [5, 6] offers prolonged labelling, and thus higher signal-to-noise ratio (SNR) perfusion measurements, than pulsed (PASL) approaches. However, the longer labelling duration in pCASL leads to increased minimum TR and worse temporal resolution than PASL. Finally, ultra-high magnetic fields (7 T and higher) have been shown to offer benefits for both BOLD [7, 8] and CBF [9] measurements. Nevertheless, the successful implementation of ASL at 7 T with temporal resolution and coverage similar to current 3 T techniques presents significant technical challenges. Taking into consideration all the aforementioned arguments, it remains open which ASL technique is most suited for simultaneous high-temporal-resolution CBF and BOLD measurements. In order to answer this question, in this study we compared a pCASL and two PASL variants at 3 T with a PASL variant at 7 T.

Methods: Experiments were performed on 3 T and 7 T Siemens scanners with 64-channel and 32-channel receive head coils, respectively. Nine subjects (5 male) participated in the study after giving informed consent. The subjects were scanned for an hour in the 3 T and immediately transferred to the 7 T, or vice versa. The acquisition parameters (bandwidth, echo spacing, partial Fourier factor, echo train duration) across techniques and field strength were matched as closely as possible and no parallel imaging was utilized. Thirteen axial slices covering the visual and auditory cortices were acquired with 3 mm isotropic resolution. The TR/TE was set to 2500/13 ms. At 7 T FAIR QUIPSS II was used, while at 3 T the following labelling schemes were applied in randomized order: PICORE Q2TIPS (PQ2T), FAIR QUIPSS II and pCASL. The inversion times for all PASL schemes were 700/1800 ms, while those for pCASL were 975/1980 ms. For all schemes a baseline perfusion and a functional scan were obtained with 96 and 120 repetitions, respectively. The functional paradigm consisted of 30 s 8Hz-flickering-checkerboard hemifield stimulation and 45 s grey screen as rest. At 7 T slab-selective or non-selective inversion was done using an optimized 10 ms tr-FOCI pulse [10]. In order to further increase the labelling efficiency at 7 T, two rectangular 18 x 18 cm^2 high permittivity 'dielectric pads' with 5 mm thickness were placed on either side of the head at the level of the temporal lobes [11]. All data were motion-corrected and coregistered within each field strength with SPM 8. Functional analysis was performed with FSL 5, whereas CBF was obtained according to equations given in [1]. Voxel-wise maps of temporal SNR (tSNR) and CBF values were averaged across all grey-matter voxels for every scan. A region-of-interest (ROI) covering the visual cortex in the stimulated hemisphere was defined, to compare the volume of significant perfusion activation between the 3 T ASL variants. This comparison could not be extended with the 7 T case, because of a different stimulation setup leading to different stimulated portion of the visual field. Paired t-tests were performed to determine the significant differences in the studied parameters between the techniques.

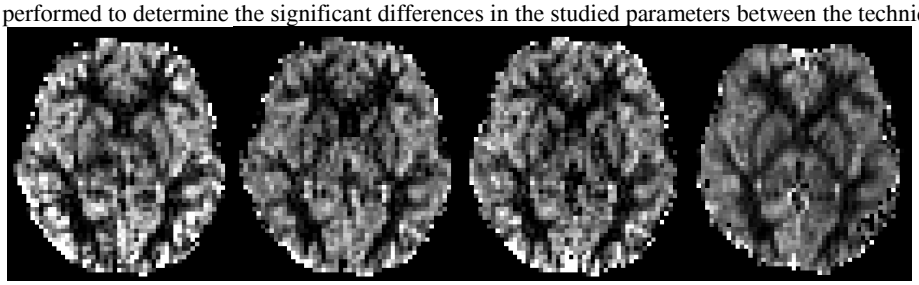

Figure 1: pCASL PQ2T FAIR 3 T FAIR 7 T

	CBF	tSNR	Number of voxels with perfusion activation
pCASL	57 ± 8	1.04 ± 0.29	138 ± 47
PQ2T	56 ± 6	0.93 ± 0.12	172 ± 42
FAIR 3 T	57 ± 6	0.98 ± 0.18	127 ± 54
FAIR 7 T	47 ± 5	0.77 ± 0.13	N / A

Table 1: Mean ± standard deviation of given values

Results: Figure 1 shows the perfusion (scaled identically) in an axial slice from each method in a representative subject. The overall appearance is similar, albeit with clear regional differences. Table 1 lists the mean and the standard deviation of CBF, tSNR across all acquired grey matter voxels and the number of significantly activated voxels in perfusion for every ASL technique. There are no significant differences between the tSNR and CBF for any of the 3 T variants, despite pCASL having the highest tSNR. In contrast, the 7 T acquisition showed significantly lower CBF ($p=0.0062$) and tSNR ($p=0.0025$) than any of the 3 T methods. PQ2T has significantly larger perfusion activation volume than FAIR ($p=0.0022$). However, the differences in perfusion activation volume between PQ2T and pCASL and FAIR and pCASL are not significant. Finally, the BOLD activation volume of the 7 T ASL was significantly larger than any of the 3 T approaches.

Discussion: The lack of significant differences between the mean CBF obtained at 3 T confirms the overall validity of the acquisition parameters and quantification model, as well as the robustness of the methods used. Furthermore, the absolute CBF values fall nicely within the previously reported physiological range. The high perfusion values in the area of the sagittal sinus in both 3 T and 7 T FAIR is due to the labelling of the venous portion of the vascular tree, a consequence of the non-selective inversion. In contrast, the high CBF values in the posterior regions of the brain in pCASL are an artefact of the short post-labelling delay used. This is done in order to achieve sufficient labelling without increasing the TR. The higher tSNR of the pCASL is in line with earlier work [1, 5, 6]. The lower tSNR in 7 T FAIR might stem from diminished labelling efficiency due to B_1- and B_0-inhomogeneities, particularly in some subjects, despite the measures undertaken to counteract them. This could also contribute to the lower CBF values at 7 T, since the labelling efficiency is a global scaling factor in the quantification. A way to further improve the labelling efficiency at 7 T in a subject-specific manner is offered by parallel transmission, or dedicated labelling coils, both beyond the scope of this work. Another reason for the lower tSNR of the 7 T ASL acquisition is the shorter grey-matter T_2^* at 7 T compared to 3 T, which leads to faster decay of the label, despite the matched acquisition parameters. However, this is also the reason for the improved BOLD sensitivity at 7 T. In conclusion, further technical improvements might be necessary for 7 T ASL to be able to reach its full potential and supersede 3 T approaches in CBF functional imaging as it has for the BOLD case.

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