Whole brain pseudo continuous ASL at 7T using a single coil for imaging and labeling.

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Introduction.
Arterial Spin Labeling (ASL) is a non-invasive method that enables brain perfusion measurement. By magnetically labeling, the blood is used as an endogenous contrast medium. In recent years several ASL techniques have been developed for and implemented on clinical scanners with a field strength of up to 3T. ASL is a technique that, in principle, suffers from a low signal to noise ratio (SNR). Therefore, the arrival of 7T whole body scanners with the promise of inherently higher SNR, presents an opportunity to improve perfusion measurements, although first experiments showed difficulties to achieve high labeling efficiencies below the brain. In this study we implemented pseudo continuous ASL (pCASL) on a 7T scanner, without changes to the hardware such as separate coils for labeling. The main topics for efficient labeling were identified and optimized with the realization of whole brain perfusion measurements through pCASL [1]. Presently, pCASL on 7T renders an SNR that is comparable to that on 3T under similar circumstances. However, SAR constraints are much tighter on 7T, leading to higher repetition times (TR). Making use of shorter TR's, such as allowed on 3T, leads therefore still to higher SNR per unit time on 3T than on 7T.

Material and methods.
On an Achieva 7T whole body scanner (Philips Healthcare, Best, The Netherlands), the conditions for labeling, like B0 inhomogeneities, RF penetration and f0-offsets, were measured at two candidate locations for labeling (directly below Circle of Willis and just above carotid bifurcation). Four healthy volunteers were scanned, 2 male, 2 female, age 26-51 yrs. With a multi slice B0 measurement (M2D GRE scan with TR/TE/ΔTE=9.2/4.5/1 ms, 1.2 x 1.2 x 4 mm voxel size, 10-15 slices), the frequency offset within the vessels was established. From these results, frequency offset and the gradient along the vessel were calculated. At the labeling location, efficiency of B1 deliverance was measured using a single slice GRE (TR/TE-250/1.8 ms, voxel size = 2 x 2 x 5 mm, flip angle = 20 – 240 deg. with increments of 20 deg.). Main parameters for pCASL were for labeling: 0.5 ms Hanning pulses with pulse interval of 1ms, label duration 1350 ms, post labeling delay 1250 ms while for imaging a multi slice, single shot EPI was applied with 17 slices, gap 1mm, voxel size 2.3 x 2.3 x 6 mm^3, TR/TE of 12500/11 ms. Inversion recovery background suppressions was applied with inversion pulses at t = -5375, t = -75 ms (t = 0 corresponds to start of labeling) and t = 1950 ms. TR of 12500 ms was chosen to apply with the stringent SAR limitations present on 7T. For comparison of SNR, a pCASL scan with identical timings and geometry was performed on an Achieva 3T scanner (Philips Healthcare, Best, The Netherlands). This scan was then repeated with shorter TR (4170 ms) to compare SNR per unit time.
Post processing consisted of calculation of perfusion maps and maps that show SNR over time, i.e. (mean) / (standard error of the mean) of the subsequent subtractions. For each subject, the 7T maps and 3T-long-TR maps were registered to the 3T-short-TR maps with SPM8. Gray matter masking of the perfusion maps was applied on a reference slice at the level of the basal ganglia. Subsequently this mask was split in three regions of interest (ROI) that covered the flow territories of the left and right carotid artery and the posterior circulation. Subsequently, these ROI's were applied to the SNR maps. For measurement of white matter SNR, ROI's were drawn in the left and right central white matter at the first slice superior of the ventricles.

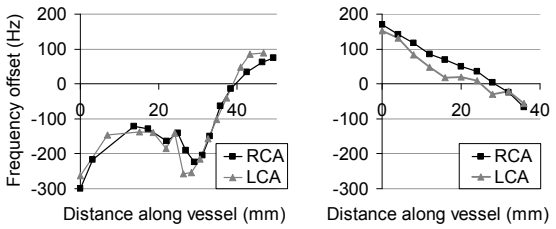

Figure 1. Example of B0 measurements along the carotid arteries. Left figure shows frequency offsets for a labeling slab that is positioned just inferior of the Circle of Willis. In the same volunteer, a slab position inferior of the basal artery results in smaller and more linear Δf.

Results and discussion.
B0 measurements demonstrated an erratic profile along the vessels when the labeling slab is positioned just inferior of the Circle of Willis, while a slab position inferior of the basal artery resulted in a more linear profile. Figure 1 shows results for the carotid arteries of a single subject. B1 measurements showed that effective flip angle within the vessels was about 60% of the nominal value at the higher label position, but dropped to half of that at the lower position because anatomy is outside the range of the standard head coil. For this study, the lower labeling position was selected, so the gradient along the vessels could easily be compensated by adjusting the mean gradient that is played during labeling. By placing two di-electric pads at either side of the head and neck, the RF coverage of the head coil was effectively stretched inferiorly, enabling adequate flip angles.
As an example, the 7T perfusion map of one subject is shown in figure 2a. Figures 2b and c show the SNR maps for the 7T scans and 3T of the same subject. Table 1 shows the results of SNR measurements in the reference slice. In gray matter 7T pCASL SNR is comparable to 3T scans with the same TR. However, when the shorter TR that is allowed on 3T was fully utilized, SNR on 3T was 90% higher than on 7T. In white matter ROI's, SNR at 7T was comparable to that of the 3T-short-TR scan, pointing at the preferable T1 of white matter at 7T compared to 3T.

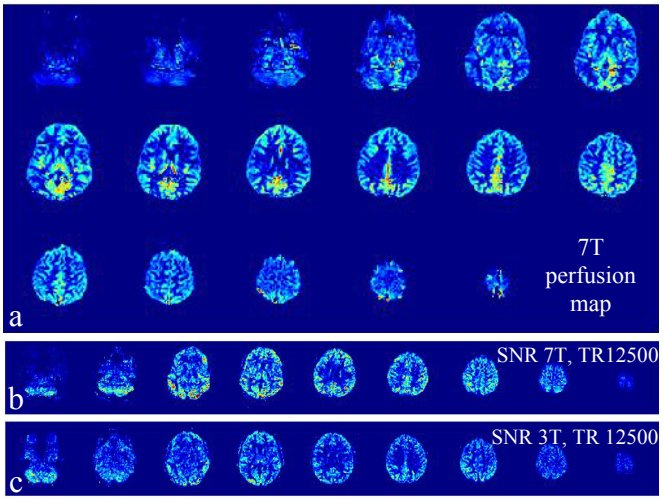

Figure 2. Results for a single subject. Top image(a) shows the 7T perfusion map. Odd slices of the SNR maps for 7T and 3T with equally long TR are shown in (b) and (c) respectively.

	GM right	GM left	GM posterior	WM right	WM left
3T, TR 4170 ms	8.73 (3.27)	9.15 (3.62)	10.04 (4.96)	1.15 (0.89)	1.51 (1.13)
3T, TR 12500 ms	4.71 (1.84)	4.87 (1.88)	5.81 (2.99)	1.11 (0.80)	1.18 (0.97)
7T, TR 12500 ms	4.89 (2.15)	5.14 (2.14)	5.80 (3.01)	1.37 (0.77)	1.60 (0.91)

Table 1. Average SNR levels (SD) for gray matter in the left, right and posterior flow territory at the level of the basal ganglia. White matter data are measured in central white matter superior of the ventricles.

This study shows that whole brain pCASL is feasible at 7T without the use of a separate labeling coil. However, it requires additional measurements of B0 in the vessels and di-electric padding for effective B1 deliverance. At this moment the most limiting factor is SAR that demands artificially high TR. However, by application of verse pulses for labeling, extension of the inter-pulse time, improved SAR modeling and improved padding, we expect to reduce TR while still within SAR-limits, hence improving SNR per unit time .

1. Garcia et al Proc. ISMRM 13, abstract 37 (2005)