Cerebral perfusion measurements at 17.2 T using pCASL: a feasibility study

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Target Audience: This abstract is intended for researchers in the field of perfusion MRI.

Purpose: The pseudo-continuous ASL approach (pCASL) mitigates the technical restrictions of continuous ASL (CASL) and typically leads to lower RF power deposition. In addition, the availability of ultra-high field preclinical scanners renders the use of pCASL attractive for cerebral perfusion measurements in small animals, as is it benefits from increased signal to noise-ratio (SNR) and longer blood longitudinal relaxation times. However, the stronger magnetic field can result in higher physiological noise and increased B0 inhomogeneity at the labeling plane, thereby limiting the inversion efficiency. The purpose of this work was to test the feasibility of using pCASL at 17.2 T.

Methods:

Animals: Experiments were performed on a 17.2 T horizontal preclinical scanner (Bruker Biospin) using a transmit/receive birdcage volume coil (diameter 38 mm). The animals (Sprague Dawley male rats, 150 – 250 g, n = 6) were anesthetized with isoflurane (1-2 % in a 1:2 O_2:air mixture) during the acquisition. The respiration rate was maintained at 50 -60 bpm.

MR acquisition: pCASL experiments were performed using the unbalanced pCASL control method[1]. The labeling plane, located in the rat neck area (~1.8 cm below the imaging slice) was placed close to the isocenter. The inversion was performed using Hanning window-shaped pulses of 400 µs duration at a repetition rate of Δt = 800 µs. Single-segment SE-EPI (FOV = 2.5 x 2.5 cm^2, slice thickness = 1 mm, matrix = 64 x 64, TE = 8.2 ms, TR = 5000 ms, number of averages = 20) was used for image acquisition. Other pCASL parameters were set as follows: 3000 ms labeling duration, 200 ms post labeling delay, labeling maximum gradient G_{max} = 45 mT/m, labeling average gradient G_{ave} = 5 mT/m, average RF amplitude = 4 µT. The optimum interpulse phase increment for maximum perfusion signal was determined by performing a pre-scan with parameters identical to those for pCASL-EPI except for the labeling duration (1.5 s) and the slice thickness (4 mm). The inversion efficiency (IE) was measured on each rat on a slice located 3 mm away from the labeling plane using a gradient echo flow compensated (GEFC) pulse sequence (FOV = 3 x 3 cm^2, matrix = 256 x 256, slice thickness = 1 mm, number of averages = 2) combined with the same labeling module as for the pCASL acquisition. T1 maps were acquired using an inversion recovery (IR) EPI acquisition.

***Data processing*:** The IE was calculated according to: $IE = \left|\frac{M_a^0 - M_a}{2M_a^0}\right|$, where M_a^0 and M_a are the equilibrium magnetization and the magnetization after inversion, respectively, measured in the two ROIs corresponding to the carotid arteries (Fig. 1a). For CBF quantification we used the following formula:

$$CBF = \frac{\lambda \Delta M \, x \exp\left(\frac{\omega}{T_1^b}\right)}{2\alpha M_0^t T_1^t x \, (1-\exp\left(-\frac{\tau}{T_1^t}\right))} \, x \, 6 \, x \, 10^6$$

, with λ the blood tissue partition coefficient for water (0.9 mL/g), ω the post labeling delay (200 ms), τ the labeling duration (3 s), α the labeling efficiency, M_0 the tissue magnetization at thermal equilibrium, T_1^t and T_1^b the longitudinal relaxation time of tissue and blood, respectively. T_1^b at 17.2 T (3200 ms) was measured by using a blood sample taken from the femoral artery of an anesthetized rat.

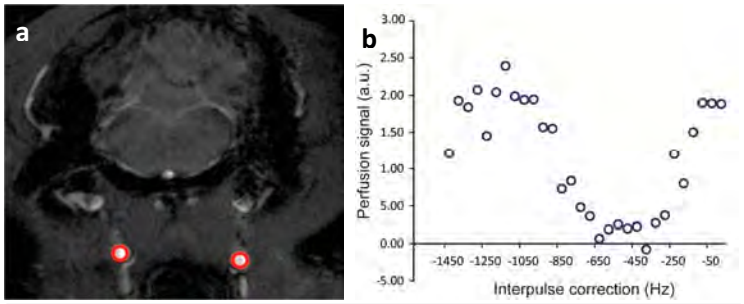

Fig.1 (a) pCASL GEFC image showing the ROIs in which the IE was measured (red circles); (b) Example of data acquired for interpulse phase optimization (the signal was averaged on an ROI encompassing the entire brain).

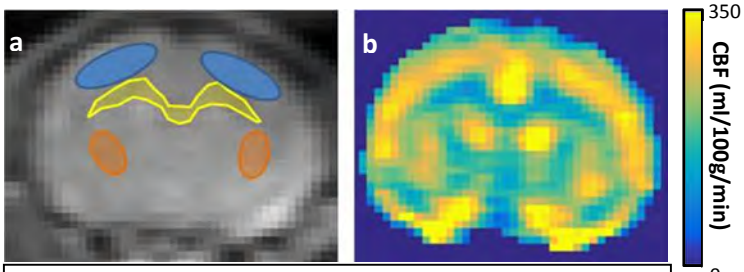

Fig.2 (a) ROIs delimitating structures for which CBF values are reported in Table 1. (b) Typical CBF map.

Results and Discussion:

Fig. 1b presents a typical example of the measurements from which the optimal phase increment was determined. For this particular animal, the optimum interpulse increment was found to be –1100 Hz (phase = 316.8°). Without this interpulse phase optimization, no reliable CBF maps could be obtained. The mean IE measured was 0.72 ± 0.05, similar to previous reports at 11.7 T[2]. Table 1 summarizes CBF values obtained in the ROIs displayed in Fig. 2a. A typical CBF map (rat3) is shown Fig. 2b. The SNR of the CBF maps was measured to be 33 ± 7.7. The average cortical CBF value found is 250 ± 14 ml/100g/min. This high CBF value can be ascribed to the use of isoflurane known to induce hypoventilation. The cortical to corpus callosum CBF ratio is 2.1 ± 0.3, in line with previous reports. In conclusion, this work demonstrates the feasibility of using pCASL for preclinical investigations at ultra-high magnetic field.

Table 1: CBF (ml/100g/min)

	Rat1	Rat2	Rat3	Rat4	Rat5	Rat6
Cortex (blue)	229.6	270.3	230.0	217.0	245.4	306.8
Corpus Callosum (yellow)	105.2	111.0	145.0	113.8	117.2	129.5
Caudate Putamen (orange)	202.8	213.4	246.8	181.6	214.8	252.7

References: 1. Dai W. et al. Magn Reson Med 2008; 60:1488–14972. 2. Duhamel G, et al. Magn Reson Med. 2012; 67(5):1225-36.