Cerebral Blood Flow using pCASL MRI and Phase Contrast Angiography in a Large Cohort

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Target Audience: Anyone interested in quantifying cerebral blood flow using MRI.

Introduction: Arterial Spin Labeling (ASL) [1] and Phase Contrast Angiography (PCA) [2] provide two independent methods for estimating the cerebral blood flow (CBF). ASL uses magnetically labeled arterial blood as a tracer to measure perfusion in the brain. Pseudo-continuous ASL (pCASL) [3] magnetically inverts flowing blood at a labeling plane, while PCA uses a bipolar magnetic gradient to encode flow velocity within vessels. In pCASL, CBF is derived from images acquired with arterial and control labeling along with knowledge about labeling efficiency and T1 relaxation [3], while PCA intraluminal velocities can be converted to CBF by integrating flow velocities across the internal carotid and vertebral arteries and then dividing the total flow by the product of the total brain volume and the average density of the brain tissue [2]. PCASL labeling efficiency is velocity dependent [2,3], and comparisons between pCASL and PCA acquired concurrently have been used to compute pCASL labeling efficiency [2,4]. In this study, we have considered ASL and PCA measurements from a large cohort of subjects from the Coronary Artery Risk Development in Young Adults (CARDIA) study for their quality assessment and to investigate the variability of the labeling efficiency in pCASL measurements.

Methods: Data from a total of 544 healthy middle-aged subjects (257 males and 287 females, age: mean= 50.46, standard deviation: 3.42) from the CARDIA study was analyzed. PCASL data were obtained using 40 label and control pairs with 1.5 sec labeling using post labeling delay=1.5 sec, 0.16G/cm gradient and 22.5mG RF irradiation applied 9 cm beneath the center of the acquired slices, FOV = 22cm, matrix = 64x64, TR = 4s, TE= 17ms and flip angle = 90°. Sixteen slices (6 mm thickness with 2 mm gap) were acquired from inferior to superior in sequential order. CBF maps were generated using ASLtbx [5]. Mean CBF maps were then visually inspected and data from 10 subjects were discarded due to artifacts. PCA data were obtained at the pCASL labeling plane for 8 phases within a cardiac cycle using velocity encoding=100cm/sec and analyzed using an in-house MATLAB program which has i) semi-automated vessel segmentation and ii) the facility of inspecting the flow profile. PCA data quality was rated as good, non-laminar and poor for each artery based on the visualization of the flow profile and consideration of the flow values. PCA data from 84 subjects were discarded due to highly non-laminar flow patterns, imaging below the carotid bifurcation, or artifacts. Brain volume was determined from the high-resolution T1-weighted 3D MPRAGE data. Brain density was assumed to be 1.06 gm/ml [2].

Results and Discussion:

1) Data from 452 subjects were considered for final analysis. The distribution of the average CBF values from the two methods is shown in Fig. 1. PCA (mean: 55.77, standard deviation: 12.04) showed higher CBF values and significantly greater variability ($F=1.48$, degrees of freedom=451, $p=3.25\text{x}10^{-5}$) than pCASL measurements (mean: 52.72, standard deviation: 9.89). Since the scans are obtained almost at the same time, this variability can largely be attributed to the measurement noise. It should be noted that PCA data were acquired in 1 min without signal averaging.

2) Fig. 2 shows average CBF values measured using PCA with respect to pCASL. Subjects are divided into two groups based on whether the average flow velocity of their arterial blood was below or above 20 cm/sec as assessed by PCA. Three different least square regression lines (one for the whole data set and two for each subgroup) are fitted to the data. The slopes, R-values and significance (p-values) of the correlations corresponding to full data set, below 20 cm/sec and above 20 cm/sec are (0.68, 0.56, $3\text{x}10^{-38}$), (0.72, 0.53, $8\text{x}10^{-29}$) and (0.58, 0.62, $4\text{x}10^{-9}$) respectively. For both velocity ranges, the points are clustered around the unity line, indicating the strong correspondence between these independent measures of CBF. However, although the observed correlations are highly significant, the considerable spread for any given flow value calls into question the use of PCA CBF to calibrate labeling efficiency at a single subject level. There is no suggestion that labeling efficiency is reduced for higher mean velocities. This is illustrated further in Fig. 3, which plots the ratio of the CBF values using pCASL to that using PCA with respect to the average flow velocity, again split by mean velocity.

Conclusion: There is substantial agreement between CBF values calculated by pCASL and PCA in a large cohort of healthy middle-aged subjects, though the correlations may not be high enough to support the use of PCA as a means of calibrating pCASL labeling efficiency in single subjects. PCA data represented a single acquisition and it remains to be seen whether signal averaging of PCA data could improve the correlations further. With the acquisition parameters used, there is no evidence that pCASL labeling efficiency falls off at higher mean arterial velocities.

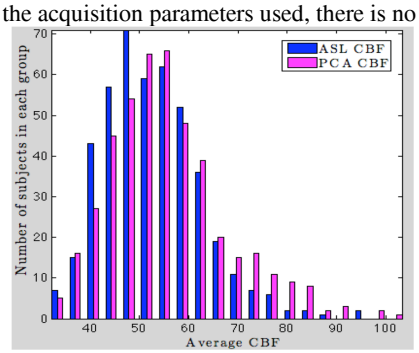

Fig. 1: Histogram of the average CBF values using ASL and PCA

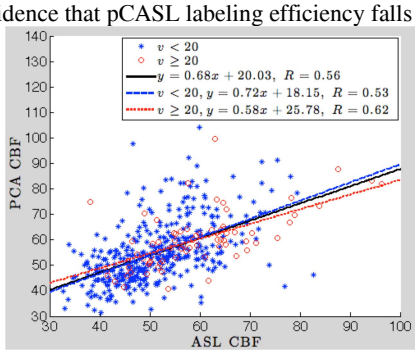

Fig. 2: Plot of the CBF values measured using ASL and PCA for each subject

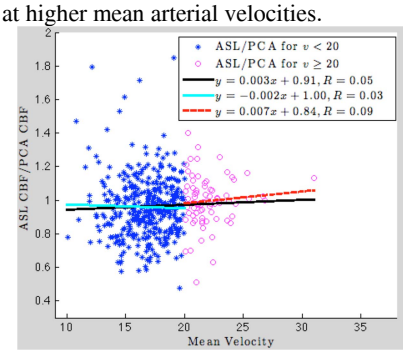

Fig. 3: Plot of the ratio of the average CBF using ASL to that of PCA with respect to mean flow velocity.

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References: [1] Detre et al. Magn Reson Med 1992; 23(1): 37-45 [2] Aslan et al. Magn Reson Med 2010; 63(3): 765-71 [3] Dai et al. Magn Reson Med 2008; 60(6):1488-97 [4] Vidorreta et al. Neuroimage 2013; 66: 662-71 [5] Wang et al. Magn Reson Imaging 2008; 26(2): 261-69.