3D High-Resolution Whole-Brain Perfusion Measurment using Pseudo-Continuous ASL at Multiple Post-Labeling Delays

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INTRODUCTION: Using the noninvasive pseudo-continuous ASL (PCASL) technique (1), quantitative mapping of cerebral blood flow (CBF) with high-resolution and whole-brain coverage has received great interest from various neurovascular applications. Perfusion weighted signals depend not only on the CBF, but also on the arterial arrival time (AAT), which is the transit time of the arterial bolus from the labeling plane to the imaging voxel (2,3). Typical PCASL scans are obtained at a single long post-labeling delay, with the assumption that the effect of AAT is small and all labels are transferred to the tissue (4). This assumption may be problematic for some regions given the heterogeneous distributions of AAT between different regions of normal brains and between normal and pathological conditions (3,5). Here, we acquired high-resolution 3D PCASL images over multiple post-labeling delays and fitted the data using a general kinetic model (2) to extract maps of CBF and AAT simultaneously.

METHODS: Experiments were conducted on a 3T Philips scanner using the body coil for transmit and a 32-channel head-only coil (Invivo) for receive. Five healthy subjects (27-47yrs) were enrolled with informed consent. The PCASL sequence was performed with 1000ms labeling duration and nine different post-labeling delays (from 300ms to 2700ms in 300ms intervals). Other PCASL parameters: RF interval 1ms, RF duration 0.5ms, and flip angle 18º, gradient strength = 6mT/m. Background suppression pulses were applied to saturate tissues with T_1s ranging from 500ms to 4300ms (1,6): a slab-selective saturation pulse right after the 3D acquisition and at 1000 ms before labeling pulses, a selective inversion at 20ms before labeling, and two nonselective inversion pulses during the post-labeling delays with timing individually tailored for each labeling delay. A 3D GRASE acquisition scheme was employed with a slab thickness of 120mm with 30 partitions along superior-inferior direction. Transverse FOV was 220x220mm^2 and acquisition resolution=3x3x4mm^3. Twenty-three EPI factors (y) with twelve TSE factors (z) were chosen to have an echo spacing of 20ms and echo train duration of 240ms. Low-high profile ordering was chosen with an effective TE=20ms. A 20ms T2-prep module with inserted motion-sensitized gradients (Venc=3cm/s) in three orthogonal directions (7) were applied before the slab excitation/acquisition to suppress signals from large vessels. Nine shots were taken to scan the full 3D *k*-space for each image. Each dataset (control and label) takes from 1-2min depending on the post-labeling delay. Total measurement time was about 15min. A 3D CSF mapping with the same resolution was performed at varying T_2 weightings to fit the scaling factor $M_{0,CSF}$ (8). A 1mm-isotropic MPRAGE scan was also included for comparison purposes. All images were skull-stripped, motion-corrected and co-registered using standard FSL routines. A general kinetic model was utilized to quantify CBF and ATT with continuous ASL. Both voxel-based and ROI-based fitting were carried using nonlinear-least-squares algorithm (Matlab). For the voxel-based analysis, maps of CBF, ATT, and R^2 of the fit were estimated. For the ROI-based analysis, the averaged signal at each delay time was fitted to report the CBF and ATT with the standard errors, and R^2 of the fit.

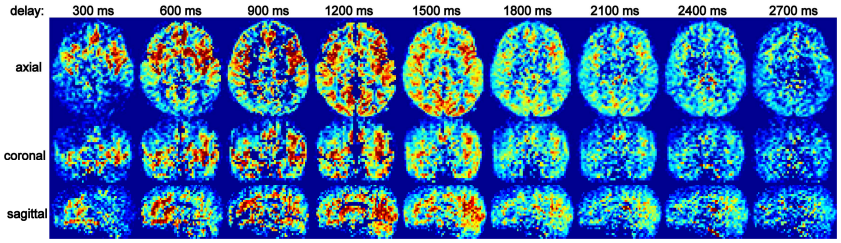

Fig.1: Perfusion weighted images (control-label) at increasing post-labeling delays.

RESULTS AND DISCUSSION: Fig.1 displays a representative data set of the difference images (control-label) with three orthogonal cross-sections, acquired at different post-labeling delays. It is observed that the arterial bolus arrives at the anterior lobe at first, then the temporal lobe, and lastly the posterior lobe. From the same slices as in Fig.1, voxel-based fittings produced CBF maps, ATT maps, and maps of R^2 of the fit (Fig.2). Co-registered partial volume estimation (PVE) of gray matter (GM) estimated from the MPRAGE images are also displayed in the right two columns. Most of the GM voxels with PVE>0.5 showed reasonable fitting results, as shown with the map of R^2 of fit. CBF maps and ATT maps only showed voxels with R^2>0.6. GM in the anterior lobe, deep GM, and WM do not show good fittings, which is either due to lack of SNR or improper use of the kinetic model. Fig.3 illustrates a representative kinetic curve fitting from the cerebellum ROI from one subject. The blue bars are the mean and standard deviation of signals across the ROI. The red line is the fitted kinetic curve. The fitted values are listed within the top right corner. Table 1 reports the CBF and ATT values (mean±STD) from different ROIs of 5 healthy subjects. CBF values are rather uniform cross regions (36~39mL/100g/min). ATT values show that arterial bolus take almost 300~400ms longer to reach occipital cortex and cerebellum than to frontal and temporal cortex, which are similar to values found in literature (3,5,9).

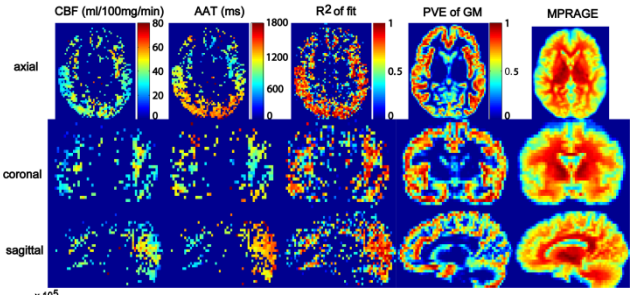

Fig.2: Maps of CBF, ATT, R^2 of fit from voxel-based fitting. PVE of GM and original MP-RAGE images are also shown for comparison.

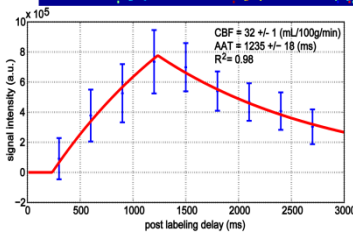

Fig.3: A representative data from a ROI fitted with kinetic model.

ROI	CBF (mL/100g/min)	ATT (ms)
Frontal	37±5	1239±389
Temporal	36±6	1366±328
Occipital	39±9	1635±270
Cerebellum	38±10	1615±276

Table 1: CBF and ATT values (mean±STD) from different ROIs of 5 healthy subjects.

CONCLUSION: We have demonstrated that 3D high-resolution whole-brain CBF and ATT maps can be obtained with PCASL at multiple post-labeling delays. The direct fitting of CBF and ATT using the kinetic perfusion model can help reduce the effect of heterogeneous ATTs in different regions.

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