Quantification of rodent cerebral blood flow (CBF) in normal and high flow states using pulsed arterial spin labeling Magnetic Resonance Imaging

S. Wegener[1,2], W-C. Wu[1,3], J. E. Perthen[1], and E. C. Wong[1]

[1]Radiology, University of California San Diego, La Jolla, California, United States, [2]Berlin Neuroimaging Center, Berlin, Germany, [3]Radiology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania, United States

Purpose: In arterial spin labeling MRI (ASL), arterial transit times (dt) - the time tagged blood takes to reach the imaging slice - may cause underestimation of CBF, particularly if flow is changed beyond baseline. Although dt correction methods have been developed for human pulsed ASL applications [1], these have not been implemented for rodent imaging. Aside from arterial transit delay considerations, it is not known how changes in the distribution and flow of blood water such as decreases in the water extraction fraction (E) and tagged blood leaving the imaging plane before image acquisition (outflow) might affect CBF quantification with PASL. We implemented a pulsed ASL technique in the rat that accounts for these sources of error, and used it to characterize the ASL signal in normal and high flow conditions in the rat brain.

Materials and Methods: Five Wistar rats were subjected to air or 5%CO_2, and Flow-sensitive alternating inversion recovery (FAIR) perfusion images were acquired. In six separate animals, arterial blood gases were obtained. For CBF calculation, we applied the double-subtraction strategy [2], in which data collected at two inversion times (TI) are combined to calculate CBF without sensitivity to dt. ASL imaging parameters were: slice thickness=2mm (3slices), gap=1mm, gap between tagging and imaging plane: 5mm, FOV=4x4cm, matrix: 64x64, flip angle=90°, number of interleaves=8, number of repetitions=10, TE= 4.3ms. Inversion times (TI): 0.3s, 0.4s, 0.6s, 0.8s, 1s, 1.25s, 1.5s, 1.75s, 2s, and 3s. TR = TI + 3.4s. ROIs were defined on anatomical images and transferred to CBF maps for CBF and dt analysis.

Results: The ASL signal fell off more rapidly than expected from TI=1s onwards, which we believe must be due to venous outflow of the tag (Figure 1). Inversion times for CBF calculation were therefore chosen to be larger than the longest transit times, but short enough (<=1s) to avoid systematic errors caused by outflow. Using our method, we observed a marked regional variability in CBF and dt, and a region dependent response to hypercapnia (Figure 2). In all ROIs except for the hippocampus, hypercapnia resulted in a robust increase in CBF. Interestingly, changes in dt were often not proportional to 1/CBF, implying a change in the total cross sectional area of the arteries with increased blood flow.

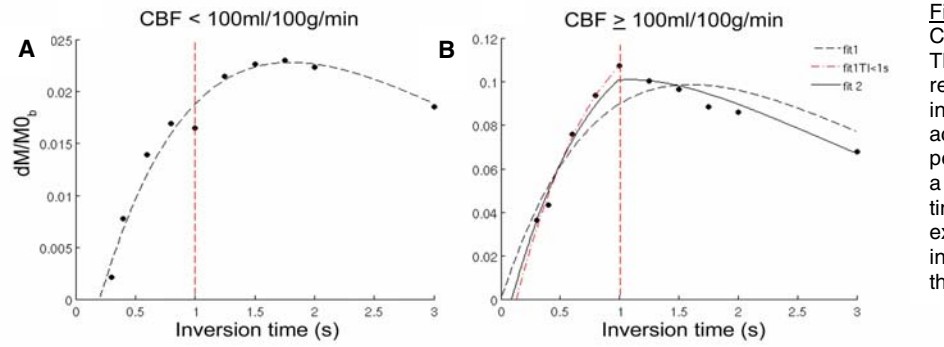

Figure 2: Mean (± SD) arterial transit times (dt in ms) (**A**) and CBF values (in ml/100g/min) (**B**) for 7 ROIs under normoxia (black) and hypercapnia (gray). * p<0.05 in paired t-test

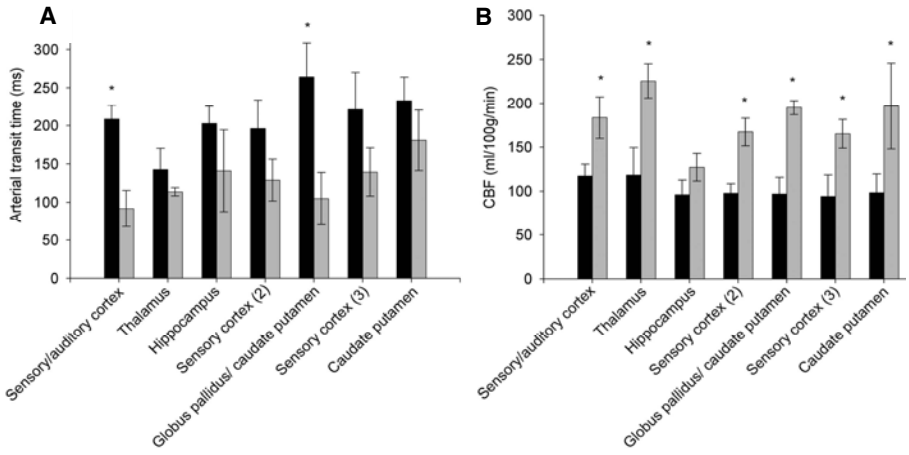

Figure 1: ASL signal course from datasets with CBF<100ml/100g/min (**A**) CBF>=100ml/100g/min (**B**). The ASL signal intensity (dM), normalized to fully relaxed blood magnetization (M0b), is plotted against inversion times (TI). Black dashed line: fitting according to the General Kinetic Model for quantitative perfusion imaging [2], solid line in (**B**): fitting including a term for incomplete water extraction (E) and outflow time (T_{out}). E and T_{out} were 0.6 and 900ms in this example. The red dashed and dotted line in (**B**) indicates fitting of data points acquired at TI<=1s using the original fitting algorithm [2].

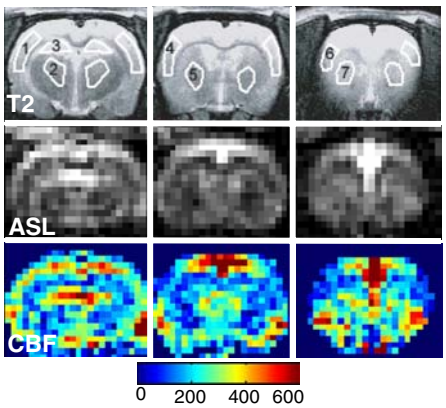

Figure 3: definition of ROIs on T2w anatomical images (upper panel) and transfer to ASL images (middle) and CBF maps (lower panel).

Conclusions:

Even when flow is accelerated, CBF can be accurately determined using pulsed ASL, as long as dt and outflow of the tag are accounted for. We observed local variations in CBF and dt over the rat brain, as well as distinct responses to a hypercapnic challenge. Accurate and locally specific CBF analyses will facilitate the understanding of how blood flow is maintained under physiological and pathological conditions.

References: [1] Wong et al. 1998. Quantitative imaging of perfusion using a single subtraction (QUIPSS and QUIPSSII). MRM 39: 702-708
[2] Buxton et al. 1998. A general kinetic model for quantitative perfusion imaging with arterial spin labeling. MRM 40: 383-396