Diffusion-Weighted Perfusion MRI: Initial Experience in Application to Brain Tumor

J. Wang[1], W-C. Wu[1], S. Wang[1], M. A. Fernández-Seara[1], K. S. St Lawrence[2], and R. D. Wolf[1]

[1]Department of Radiology, University of Pennsylvania, Philadelphia, PA, United States, [2]Lawson Health Research Institute, London, ON, Canada

Introduction Emerging evidence has suggested a limited degree of water exchange between the vascular (capillary) and tissue compartments, especially in the central nervous system. Quantification of water extraction fraction and permeability may provide clinically relevant information regarding the functional status of the blood brain barrier (BBB). Diffusion-weighted (DW) arterial spin labeling (ASL) methods have been proposed for this purpose by differentiating the amount of labeled water in the vascular and tissue space based on their distinct diffusion characteristics (1, 2). However, the reliability of the DW ASL method is hindered by the intrinsically low ASL signal and temporal fluctuations caused by eddy currents of diffusion gradients. Capitalizing on recent technical advances in pseudo-continuous ASL (improved labeling efficiency), background suppression technique (improved temporal stability), array imaging (increased sensitivity) and twice-refocused spin-echo diffusion weighting scheme (reduced eddy current), here we demonstrate that high quality DW perfusion images can be obtained with systematically varied b values up to 200s/mm^2. Initial clinical applications to high grade brain tumor showed promising results.

Materials and Methods The DW ASL sequence was a hybrid of pseudo-continuous ASL (pCASL) (3,4), background suppression (BS) and a twice-refocused spin-echo (TRSE) diffusion sequence (5) (Fig. 1). The tagging/control duration for pCASL was 1.5s which consisted of 1600 selective RF pulses (Hanning window, peak/average B_1=5.3/1.8μT, duration=500μsec and peak/average G=6.0/2.3mT/m). BS utilized two non-selective hyperbolic secant (HS) pulses appropriately spaced (determined by simulation) to suppress both gray and white matter signals to <10% of their original intensities (for the first imaging slice). Three delay times were tested: 900, 1200 and 1500ms. For TRSE, two pairs of bipolar gradients were applied along the slice direction, with the RF refocusing pulses dividing each bipolar pair. The durations of the four lobes of bipolar gradients were optimized to minimize eddy currents. Series of b values were tested, i.e., b=0, 5, 10, 25, 50, 100 and 200 s/mm^2. MR scanning was conducted on a Siemens 3.0T Trio whole-body scanner, using a product 8-channel head array coil. Acquisition parameters were: FOV=22cm, matrix=64x64, bandwidth=3kHz/pixel, 6/8 partial k-space, TR=4sec, TE=55ms. Six slices (8mm thickness with 2mm gap) were acquired from inferior to superior in a sequential order. The raw EPI images were pair-wise subtracted followed by averaging across the image series to form the mean ASL perfusion images (ΔM). The mean ΔM and raw EPI (M) signals were measured within the gray matter ROIs (segmented using SPM), and were fitted according to a bi-exponential model (1,2). The DW ASL method was also applied in the case of a patient (39yrs, male) with recurrent Glioblastoma Multiforme (GBM). Two DW ASL scans were acquired with b=0 and 50s/mm^2, and the ratio of these two ΔM images (b50/b0) provided an estimation of the tissue fraction of labeled water (TF), since the gradient of b=50s/mm^2 spoiled 99% labeled signals in the vasculature while preserving 95% of the slow component (tissue) signal (2).

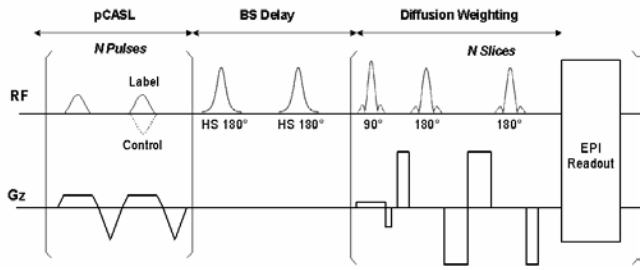

Fig. 1 Sequence diagram combining pCASL, BS and TRSE methods.

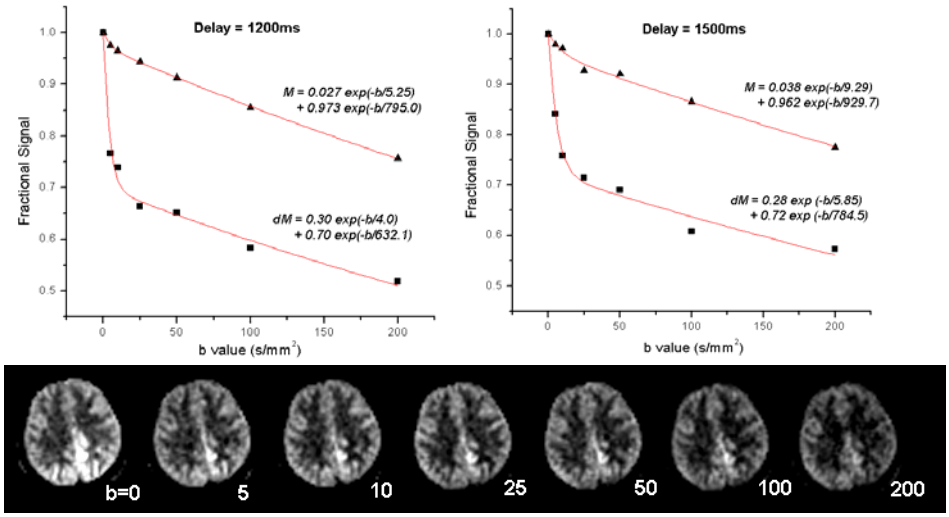

Fig. 2 Attenuation curves and representative images of DW ASL ΔM signal as a function of b value.

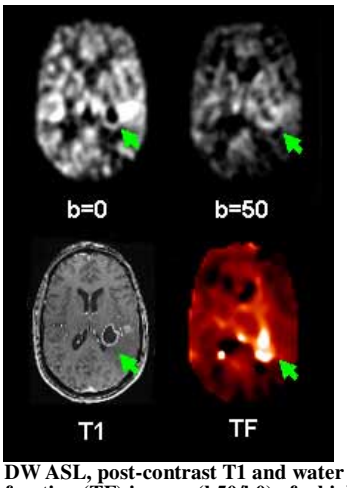

Fig. 3 DW ASL, post-contrast T1 and water tissue fraction (TF) images (b50/b0) of a high grade glioma (arrow).

Results The ΔM signal curves of a healthy subject (37yrs, female) are shown in Fig. 2, which can be fitted nicely with a bi-exponential decay model (R>0.99). The fraction of label signals in the tissue compartment (slow component) increased from 57 to 70 and to 72% when the post-labeling delay time was increased from 0.9 to 1.2 and to 1.5s. High quality DW ASL images were obtained in all 6 slices with the 3 delay times (Fig.2). The TF can be related to water permeability by $TF = \left(PS_w/V_c\right)/\left(PS_w/V_c + R_1\right)$ (2), where R_1 = 0.8 s^{-1} in gray matter at 3T, PS_W is the water permeability surface-area product and V_c is the capillary blood volume. Assuming a V_c = 1.5ml/100g, PS_w = 175 ml/100g/min for an average TF = 0.71. For the patient with recurrent GBM, a two-point DW ASL measurement (b=0 and 50s/mm^2) was performed. Enhanced tumor perfusion was observed in the two DW ASL images (Fig. 3) as well as increased water tissue fraction (suggesting increased water extraction and BBB permeability), which were concordant with signal enhancing regions on post-contrast T1 weighted images.

Discussion The present study took advantage of improved labeling efficiency using pCASL (ΔM signal ~50% greater than pulsed ASL), high sensitivity of array coil (~2 fold compared to volume coil), greater temporal stability using BS (3-5 fold compared to image series without BS) and reduced eddy current using TRSE sequence. DW ASL images with diagnostic quality can be obtained with large b values and long post-labeling delay times on individual subjects. As a novel contrast mechanism, DW perfusion MRI may provide information regarding the functional status of the microvasculature as well as the exchange of water between capillaries and tissue.

Reference

[1] Silva A et al., *Magn Reson Med* 38:232-237, 1997. [2] Wang J et al., *JCBFM* 2006 (Epub). [3] Wong EC, *Proc ISMRM*, 14:668, 2006. [4] Garcia DM et al., *Proc ISMRM* 13:37, 2005. [5] Reese TG et al., *Magn Reson Med* 49:177-182, 2003.