Water Exchange Rates in Grey and White Matter Measured by Diffusion-Weighted Perfusion MRI

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Introduction Measuring water transport across the blood-brain barrier (BBB) can improve the accuracy of contrast-enhanced MRI and has the potential to characterize BBB disruptions prior to that observed using larger molecules (1,2). The rate of water exchange across the BBB can be determined using diffusion-weighted (DW) arterial spin labelling (ASL) to determine the vascular and tissue fractions of labelled water, and a tracer kinetic model to characterize the exchange between the two pools (3-5). The goal of this study was to determine water exchange rates in grey and white matter. A pseudo-continuous ASL technique was implemented to enhance the sensitivity and DW-ASL data were collected at multiple post labelling delays to determine arterial transit times (τ_a) for both tissues (6).

Materials and Methods Experiments were conducted on a Siemens 3.0T Trio scanner using a product 8-channel head array coil. The DW-ASL sequence incorporated pseudo-continuous ASL (pCASL), background suppression (BS) and twice-refocused spin-echo diffusion weighting (6) (Fig. 1). The pCASL labelling/control duration was 1.5s, consisting of 1600 selective Hanning pulses (peak/average B_1=5.3/1.8μT, duration=500μsec and peak/average G=6.0/2.3mT/m). Acquisition parameters were FOV=22cm, matrix= 64x64, bandwidth=3kHz/pixel, 6/8 partial k-space, TR=4sec, TE= 55ms. Six axial slices (8mm thickness with 2mm gap) were acquired. The EPI images were pair-wise subtracted followed by averaging across the image series to form average ASL perfusion images (ΔM).

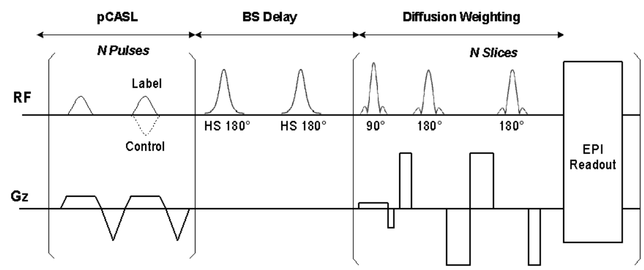

Fig. 1 Sequence diagram combining pCASL, BS and TRSE methods.

DW-ASL data were acquired with four post-labelling delays (900, 1200, 1500 and 1800ms) and seven b values (0, 5, 10, 25, 50, 100 and 200 s/mm^2). Mean ΔM signals were extracted from grey and white matter regions that were manually segmented by a neuroradiologist (S.W). At each delay time, the average DW ΔM values were fitted with a bi-exponential model to determine the vacular and tissue fractions of the ASL signal (4). A two-parameter fit of a water-exchange model (5) to the vascular fraction was used to generate best-fit estimates of τ_a (i.e., the time for the label to reach capillaries) and the water exchange rate (k_w), which is defined as the permeability-surface area (PS) product divided by the fraction of cerebral blood volume (CBV) in which exchange with the surrounding tissue occurs (CBV_{ex}). CBV_{ex} includes capillaries, arteries and venules, and is expected to be smaller than the total CBV. DW-ASL data were acquired on 5 healthy volunteers, one of whom had a developmental venous abnormality (DVA) that was analyzed separately.

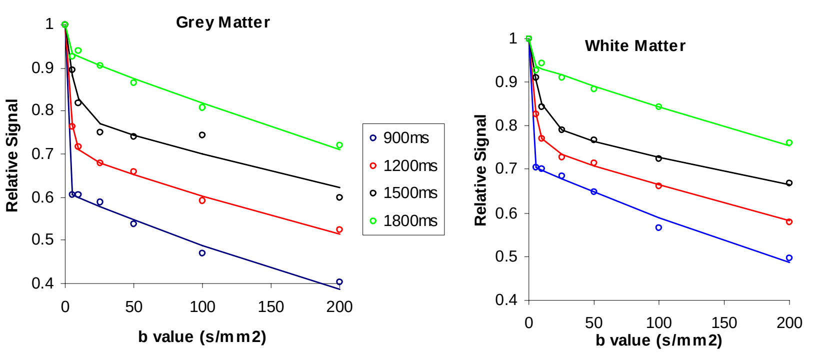

Fig. 2 Attenuation curves from the DW-ASL ΔM images for grey and white matter ROIs.

Results Average DW ΔM curves for grey and white matter at the 4 post-labelling delays are shown in Fig. 2, along with the best-fit of the bi-exponential decay model. The vascular fractions for grey and white matter and for the DVA case are plotted in Fig. 3 as a function of post-labelling delay. Included are the curves from the water-exchange model. The best-fit values of τ_a and k_w are provided in Table 1

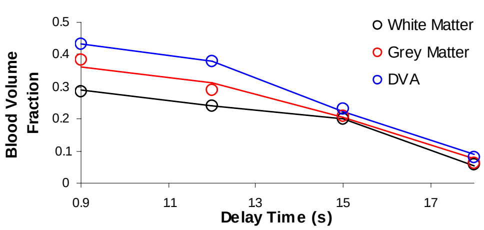

Fig. 3 Vascular Fraction determined from DW-ASL data, along with the best fit of the water-exchange model.

Tissue	τ_a (s)	k_w (min^{-1})
White Matter	1.5	262
Grey Matter	1.4	181
DVM	1.3	129

Table 1: Best-fit values from the fitting procedure

Discussion With the increased sensitivity of the DW-ASL sequence, the tissue-specific water exchange rates in grey and white matter ROIs could be determined. The higher k_w value for white matter compared to grey matter can be explained by considering that k_w is defined as PS/CBV_{ex}. Previous MRI and position emission tomography studies indicate that the white-to-grey matter CBV ratio is smaller than the corresponding PS product ratio (7,8). The DVA had the lowest water exchange rate, which was expected due to an increased flow of non-exchanged labelled water into enlarged veins. Future studies will focus of further improvements to the DW-ASL technique in order to generate images of water exchange.

Reference

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