Arterial blood volume and blood volume changes measured using ASL in humans.

C. Hoad[1], S. Francis[1], P. Gowland[1]
[1]School of Physics and Astronomy, University of Nottingham, Nottingham, United Kingdom

Introduction

Original models of the BOLD effect [1] assumed blood volume changes on neuronal activation were localised to the venous component. It is now becoming accepted that CBV changes also take place on the arterial side with changes in flow being accommodated on the venous side by increasing velocity rather than simply ballooning of the vessels [2]. Currently no direct, non-invasive measurements of the arterial component of cerebral blood volume (CBV_a) have been made in humans. This study used the EPISTAR pulsed ASL technique with a previously described [3] model for the capillary/arteriole signal to measure resting cerebral blood flow (*f*), and changes in CBV_a during a motor task activation study.

Methods

Image acquisition: Experiments were performed on 3 healthy volunteers using an in-house built, 3.0 T scanner. A multislice EPISTAR sequence was implemented with TR= 3 s and TE= 35 ms; five transaxial slices (64 x 64 matrix, 4 x 3 x 6 mm^3 resolution, 1.25 kHz switching frequency) were acquired in ~ 300 ms, with the most superior slice being acquired first. There was a gap of 15 mm between the tag and control slabs and their adjacent image slices. Immediately prior to the inversion pulse, a presaturation slab was applied, extending 10 mm beyond the imaging slab in each direction. Images were acquired with either no diffusion weighting (NDW), retaining arterial signal, or with diffusion weighting (DW), using a bipolar gradient pulse with first order gradient moment (I) of 1.5 $radm^{-1}s$, which would suppress the arteriole component of the signal.

Paradigm: Two experiments were performed; (i) A rest experiment where (to shorten the experiment) only DW data were acquired, at slice 1 inversion times (TI's) of 220, 370, 520, 720, 920, 1120, 1420, 1820 ms. 20 ΔM maps (control-tag image) were acquired per TI. (ii) An activation study using a finger tapping task where NDW data were acquired for the shortest six TI's. This study comprised 4 cycles of activation and rest. During each cycle 6 ΔM images were acquired for each activation state (24 ΔM image pairs per state, per TI). Rest DW (i), and rest/activation NDW (ii) studies at each TI were interleaved. T_1 maps were acquired using a non-selective inversion recovery sequence with 13 TI's (50 -4000 ms).

Analysis

Images were motion corrected using a 2D rigid body model to take into account the signal attenuation from the saturation recovery. Tag and control images were subtracted to yield difference (ΔM) images for each TI. At each TI, the activation NDW ΔM signals were correlated with a haemodynamic response function (HRF) (formed by convolving the stimulus waveform with a Poisson function with λ of 6 s). The correlation maps for the early TIs (220, 370, and 520 ms) and late TIs (720, 920, and 1120 ms) were separately combined to form two correlation maps, $p < 0.05$ (corrected) (Fig. 1). BOLD activation was also identified using the control data (combining maps created at different TIs separately). For regions identified on the early TI data sets (which are expected to be dominated by arterial volume changes), average ΔM signals were plotted, (Fig. 2). To measure the resting capillary flow, *f*, and transit time, Δ_c the average DW perfusion data for the ROI was fitted to a simple model [3]. Using these fitted parameters the underlying capillary contribution to the signal was removed from the NDW time courses (assuming that *f* increased and Δ decreased by 25% on activation; see discussion). For regions activated at early TIs, assuming that the arterial blood is not exchanging with the tissue water, resting CBV_a (as a fractional of total brain water) was calculated at each TI by subtracting the DW rest data from the NDW rest data, and then correcting for the T_{1blood} recovery of tagged magnetization. The resulting CBVa time courses (fug3) were fitted to a cubic spline to estimate the maximum CBV_a on rest and activation

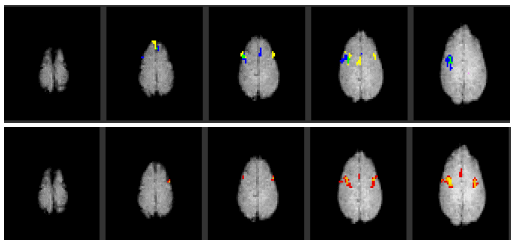
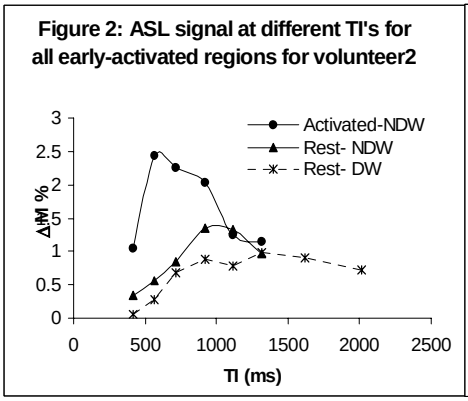
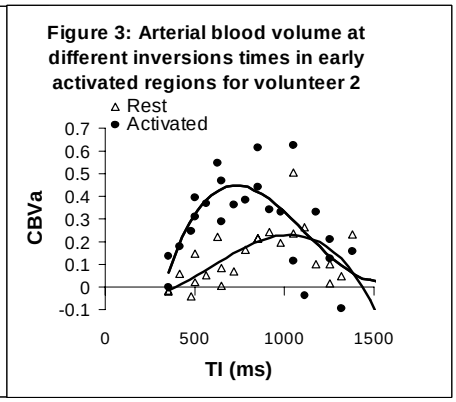


Figure 1 Top row: Activated regions (corrected $p < 0.05$) for ΔM signals at early (blue)and late TIs (yellow), and overlapping areas (green). Bottom row: BOLD activation.





Results

Figure 1 shows the statistical parametric maps for volunteer 2. Figure 2 shows the ΔM ASL signals. Figure 3 shows the variation in calculated CBVa with TI. Table 1 summarizes the numerical results for f and CBV_a at rest and on activation.

Discussion and Conclusions

This abstract presents a potential method for non-invasively measuring arterial blood volume changes in humans. The data suggests that that the fractional changes in CBV_a on activation is large (~50%), whilst the measured absolute value of CBV_a (~0.4%) is smaller than expected (~1.3% estimated using [4] and [5]). The assumed change in *f* and Δ_χ on activation will have introduced errors in the change in CBV_a. In future DW data will be acquired for both rest and activation conditions to overcome this, or the change in Δ will be determined from the data. The underestimation of CBV_a may arise from the implicit assumption that the arterial input function is a box car, whereas in fact it will be a smooth function. Future work will focus on using a more complete model linking the arterial and capillary components.

	Vol. 1	Vol. 2	Vol. 3
CBVa (act)	0.63	0.45	0.46
CBVa (rest)	0.43	0.23	0.50
Average *f* $mlmin^{-1}100g^{-1}$	26 (N=5)	44 (N=9)	58 (N=3)

References [1] R.B. Buxton, *et al.*, MRM, 39, 855-864, 1998. [2] S-P. Lee, *et al.*, MRM, 45, 791-800, 2001.[3] A. Sleigh, *et al.*, Proc. Intl. Soc. Mag. Res. Med. 10, 1058, 2002 [4] Duong, Magn Res Med, 43, 393-402 2000, [5] H An and W Lin, Mag. Res. Med., 47, 958-966, 2002.

FUNDED BY THE MRC, UK