Effects of CBV and Capillary Permeability on ASL Signal

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Introduction

Arterial Spin Labeling (ASL) has been utilized to measure cerebral blood flow (CBF) based on biophysical models. However, none of the existing models considered the influence of cerebral blood volume (CBV) on CBF measurement using ASL [1, 2]. It has been shown that CBV increases 20-40% accompanying with brain activation [3], but whether the change of CBV affects ASL signal remains unknown. In this study we investigate the contributions of CBV and capillary permeability on the pulsed ASL (PASL) signal using a two-compartment (2-comp) model [1].

Methods

Two compartments were considered: extra-vascular (EV) and blood compartments. The total magnetization (M) was the sum of the magnetization from each compartment weighted by their volume fractions (Ve and Vb): **M=Ve*Me+Vb*Mb**. Among these parameters, the venous outflow were considered in two scenarios: 1) Fast perfusion ($\Delta Mv = \Delta Mb$): assuming the venous outflow has same magnetization as in the capillary (CBV/CBF < TI) and 2) slow perfusion ($\Delta Mv = 0$): assuming labeled water never leaves the voxel during the measurement time (CBV/CBF > TI). The following simulations were based on a general solution derived from the Bloch equation with 0~25% CBV changes (corresponding to 0~70% CBV changes according to the Grubb's equation), permeability surface-area product (PS) values ranging from 1~700 ml/100g/min. Other resting physiological and biophysical parameters were listed in Table 1.

Results

CBV Effect (Fig.1) – CBV contribution was defined as the extra PASL signal change induced by CBV changes during neural activity comparing to the PASL signal change without CBV effect. CBV contribution to ASL is less than 0.8% in slow perfusion, while it reaches 6.6% in the fast perfusion. This result indicates that CBV affects the PASL signal sizably under the fast perfusion scenario. Permeability Effect (Fig.2) – Given the PS values from 1~700 ml/100g/min, the permeability effect is able to induce 8.2% CBF variation in slow perfusion and 0.5% in fast perfusion.

Parameters	Value
CBFr	60 ml blood/100g/min
CBVr	5 ml/100g tissue
PS	150 ml water/100g/min
ρb	0.89 ml water/ml blood
ρe	0.87 ml water/ml extra-vascular space
T1b	1.63 s
T1e	1.21 s
α	0.9
TR	4 s
TI	1.4 s

Table 1 Definition of bio-physical parameters at 3T

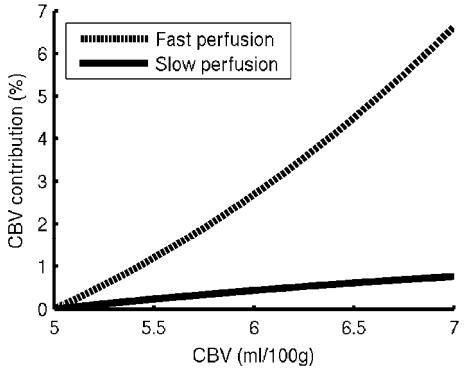

Fig. 1 The percentage CBV contributions on PASL signal followed by Grubb's equation. Fast perfusion scenarios refers to the magnetization in venous outflow equals to that in capillary ($\Delta Mv = \Delta Mb$); while slow perfusion assumes no venous outflow magnetization ($\Delta Mv = 0$).

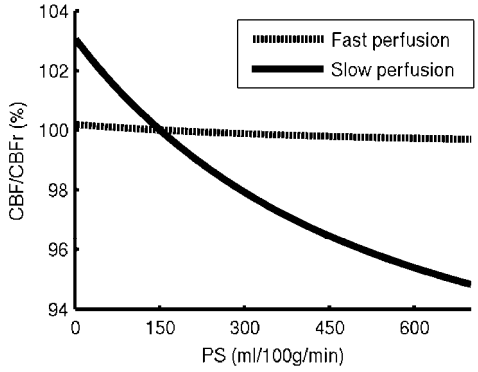

Fig. 2 The relative CBF variation induced by varying permeability surface-area product (PS) values under the two perfusion scenarios.

Conclusion and Discussions

CBV and permeability effects on PASL signals was simulated in the current work using the 2-comp model under fast and slow perfusion cases. Generally, these effects are relatively small when comparing to the CBF effect itself. However, these physiological effects might induce up to 8% variations if a precise CBF quantification is concerned, depending on which scenario is observed. The slow perfusion can be assumed in human studies because the mean transit time in human is around 5 s (CBV/CBF = 0.05/0.01). For small animals, the fast perfusion would be favorable since the CBF in rats was reported as 2-3 folds faster than that in humans while their CBV was similar to human's. Henceforth, CBV effect might have more influence on the estimated perfusion in animal models, while permeability might have more effect on human subjects. The permeability surface-area product may not change during neural activation, but varies under pathological conditions such as tumor developments. These effects should be taken in account for studies requiring accurate CBF measurements.

References

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