Effects of water exchange and venous outflow on VASO contrast: a theoretical study

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Introduction: Vascular space occupancy (VASO) is a recently purposed functional imaging method for measuring changes in the cerebral blood volume (CBV)[1]. Signal contrast associated with CBV is achieved using the difference in the T_1 relaxation times between blood and tissue. By nulling the blood signal at the acquisition time, the measured decease in the tissue signal during neuronal activation is attributed to the concomitant increase in CBV. To determine the activation-induced changes in CBV, the VASO signal is modelled as two non-communicating compartments for water magnetization in blood and tissue. As noted in the original paper[1], this model is an approximation, as it does not account for a number of processes including water exchange between blood and tissue. The purpose of this work was to investigate this potential problem further using tracer kinetic models that account for water exchange in the microvasculature.

Theory: Two tracer kinetic models were used in this study. (1) The one-compartment model treats the microvasculature and surrounding tissue as a single compartment by assuming fast water exchange[2]. This is the model used in arterial spin labelling studies[3]. (2) The exchange model accounts for finite water exchange, different T_1 values in blood and tissue, and the different components of the vasculature (Fig. 1)[4].

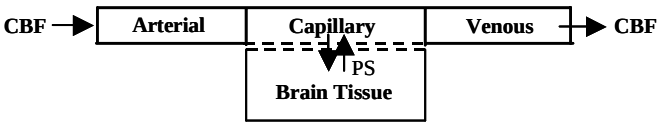

Fig.1 Major compartments of the exchange model. Water transport due to flow occurs only in the vasculature and water exchange between capillaries and tissue is characterized by the permeability-surface area product (PS).

Using these models, potential signal changes during activation, other than the VASO effect, were investigated. Simulations were conducted assuming resting-state CBF = 60 ml/100g/min, 75 % increase in CBF during activation, PS = 150 ml/100g/min, water partition coefficient = 90 ml/100g, tissue T_1 = 0.9 s, blood T_1 = 1.35 s, and capillary and total CBV = 2 and 5 % of the brain volume, respectively. Simulations were conducted over a range of inversion times ($0.7 \leq TI \geq 1$ s) and venous CBV ($0 \leq CBV_v \geq 60$ % of CBV).

Results: The predicted signal change, $(S_{act}-S_{rest})/S_{rest}$, as a function of TI is shown in Fig 2 for both models. For comparison, the reported VASO signal at TI = 0.92 s is -0.7 %[1]. Both the one-compartment model and exchange model with a small venous volume predict a significant signal change due to the efflux of venous blood. However, since the CBV_v is considered the largest fraction of CBV, these predictions are probably overestimating the effect. When CBV_v = 60 % of the total CBV, then the simulations predict negligible errors. At this CBV_v value, the venous transit times at rest and during activation are larger than the TI values and consequently, there isn't sufficient time for tissue water to exit via venous outflow.

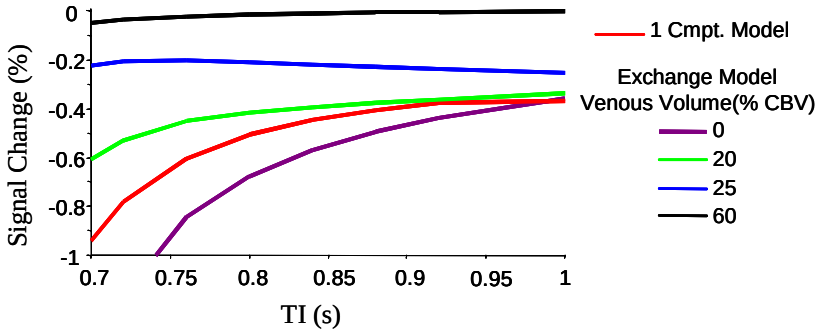

Fig.2 Predicted signal change as a function of TI. Data are presented from both the one-compartment and exchange models. Simulations with the latter were conducted over a range of the venous blood volumes.

Conclusion: Using a tracer kinetic model that realistically models water transport in tissue, we have attempted to characterize any potential errors with VASO due to water exchange and outflow. Our simulations predict that these errors are expected to be small provided the venous transit time is longer than the chosen TI value. The exchange model could be used to investigate other effects that could contribute to the VASO contrast, such as incomplete recovery of the longitudinal magnetizations in the various compartments due to a short TR value.

References

(1) Lu et al., *Magn Reson Med* 2003;50:263-274
(2) Kety., *Pharmacol Rev* 1951;3:1-41
(3) Detre et al., *Magn Reson Med* 1992;23:37-45
(4) St Lawrence et al., *Magn Reson Med* 2000;44:440-449