Sensitivity to bolus dispersion in continuous and pulsed multi-TI ASL techniques

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Introduction. In both clinical and research settings, arterial spin labeling (ASL) is used to provide information on regional CBF non-invasively using MRI. In elderly patients and those with cardiovascular disease, variable transit delays and label dispersion lead to bias in CBF measurements. The magnitude of the bias, therefore, is a function of the status of the disease which undermines comparisons across subjects and determination of absolute thresholds for normal and abnormal regional CBF. Several models have been proposed to describe delay and dispersion in pulsed and continuous ASL experiments1,2,5 as well as deconvolution-based model free Quasar ASL to avoid such modeling all together6. These techniques rely on acquisition at multiple inversion (TI) times. Radiologists, MRI researchers and scanner manufacturers are, consequently, interested in determining which of the ASL techniques is capable of handling the issue most effectively. To address this question Gaussian dissipation and single compartment Kety models are typically employed3,6. However, both were found to be inadequate for description of ASL experiments because (i) bolus disperses continuously as it travels down the vascular tree and must be modeled as such all the way to the capillary level and (ii) exchange through the capillary wall is not instantaneous7.

The purpose of this work is to evaluate accuracy of ITS-FAIR5, QUASAR8 and CASL2 multi-TI methods using a recent model of continuous bolus dispersion9 and restricted water permeability of capillary walls5 which was found to match the experimental data well3.5,9

Methods. The vascular tree, starting from the level of small arteries down to capillaries, can be described by a space-filling fractal1. Number of vessel bifurcations in the delivery, arterial and microvascular compartments was set to 2, 5 and 18 respectively9 (see Fig.1a). Identical vessel geometry and initial 1sec-long bolus were used in all simulations. Partial label saturation due to repeated excitations of the Look-Locker train in ITS-FAIR and Quasar was simulated by a decaying exponential1, exp(-ΔTI), where ΔTI=ln(cos(ϕ)/ΔTI). ϕ is its flip angle and ΔTI=200ms is its time step. Signal in CASL was simulated at the same set of multiple single TIs, where label does not suffer such saturation. Flow crushing gradients are simulated by excluding signal contribution from the arterial compartment where blood speed is high. In our vascular tree model this corresponds to 3cm/sec crushing velocity cutoff.

Results. Degree of bolus dispersion as it travels down the vascular tree is demonstrated in Fig.1b. Ratio of the estimated to true flow is shown in Fig.2a,b. Simulated signals and fits are shown in Fig.2c,d. Quasar fits data perfectly by the virtue of the method4, thus not shown.

Discussion. The fits of the CASL2 and ITS-FAIR5 models to the data are not perfect, but certainly not bad enough to explain the discrepancy in the flow estimation. ITS-FAIR and CASL perform well in the absence of flow crushing gradients because simulations do not include pass-through vessels. In practice, flow crushing is used to suppress pass-through vessels carrying blood to other voxels.

Conclusion. Simulations reveal that Quasar at ϕ=20°, ΔTI=200msec, handles bolus dispersion most effectively while CASL and ITS-FAIR demonstrate similar 30-50% CBF underestimation, which is known to be caused by unaccounted bolus dispersion10. Such underestimation worsens in cardiovascular diseases which may cause even greater bolus dispersions than simulated in this study.

References: