Realistic Model of Partial Volume Effect on the AIF in Dynamic Susceptibility Contrast Perfusion MRI

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Introduction

Perfusion measurements with the dynamic susceptibility contrast (DSC) depend critically on a reliable arterial input function (AIF). Ideally, the AIF is estimated from the relaxation effect of contrast agent (CA) in a voxel in a feeding artery, (1,2). The resolution of images used in the DSC MRI restricts the possibility to find such voxels to the largest carotid arteries. Large arteries, however, display apparent shifts during the bolus passage when observed with EPI-based sequences and complete loss of blood signal at echo times optimized for tissue contrast. Finally, the AIF undergoes delay and dispersion downstream of the measurement site, affecting resulting perfusion parameters. Selection of the AIF closer to the tissue of interest (3,4) involves small arteries with a significant partial volume effect (PVE) with brain parenchyma. Thijs et al. (5) found large variations in the size of cerebral blood flow (CBF) abnormality when the AIF measurement was taken in different arteries. The variability in the measured AIF is believed to be caused by delay and dispersion of the AIF, flow effects, the PVE and the orientation of the artery in the voxel. All these issues lead to poor accuracy and low reproducibility of the AIF measurement (6, 7).

In this study we predict the influence of PVE on CBF and the cerebral blood volume (CBV) using a realistic model of MR signal relaxation.

Theory and Methods

In this study we consider arteries parallel to B_0. The artery is described as a long cylinder that does not induce magnetic field gradients in the extravascular space. Consequently, the signal is the sum of the blood signal with the weight equal to the PV of blood, v, and the signal from parenchyma with the weight 1-v. For a given input bolus of CA with a concentration $c(t)$, the blood signal was calculated using the nonlinear relaxation effect of CA found in in vitro experiments by van Osch et al. (8). The CA bolus was simulated as the gamma variate function (with α=3, β=1.5, (9)). The peak concentration in blood was C_0 = 18mM, corresponding to a dose of 0.1mmol GdDTPA/kg b.w. (10). The tissue concentration of CA was calculated as a convolution of the arterial concentration with an exponential residue function (mean transit time, MTT = CBV/CBF) with a delay of 1sec. The tissue signal is modelled as in (11,12) using the parameters for the brain grey matter (CBF = 60ml/100g/min, CBV = 0.04) and the gradient echo measurement with T_E = 45msec and T_R = 1.5sec. The perfusion quantities were obtained using standard methods (SVD with a threshold of 0.2, (13)). The simulation was repeated 1000 times for different noise realizations with the SNR=20.

Results

Figure 1 shows the simulated signal time course for different v. The kink on the front flank of the bolus is seen for the time moment at which the tissue signal becomes dominant, a feature observed experimentally e.g. as indicated by the arrow in the data by Atle Bjørnerud presented in Figure 2. Figure 3 and 4 show the CBF and CBV normalized on their true values. The overestimation of CBF and CBV due to the PV depends on the peak concentration of the bolus due to the fact that the larger difference between the blood signal and the tissue signal the stronger overestimation, data not shown.

Figure 1

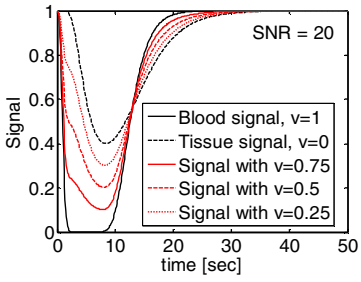


Figure 2

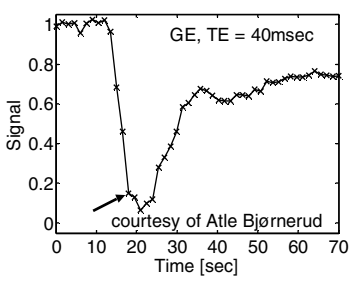


Figure 3

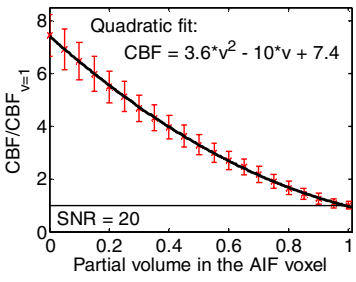
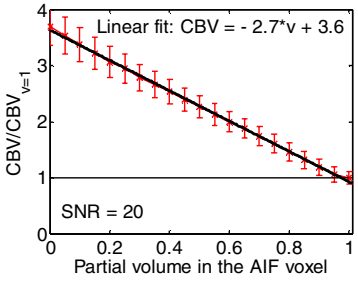


Figure 4



Discussion

Chen et al. (14) performed similar simulations for arbitrary oriented vessels but did not use realistic parameters for the blood and tissue signals. Our results predict a significant overestimation of the CBF and CBV due to the PVE. Qualitatively, this follows from the deconvolution with an underestimated AIF. The nonlinear form of the CBF curve introduce a complex dependence of the MTT on the PVE of blood according to MTT=CBV/CBF. The present results demonstrate the significance of corrections for the effect of PV with an account for actual relaxation properties of the tissue on both the shape of AIF, the concentration of CA and the perfusion parameters.

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