Analysis of Partial Volume Effects on Arterial Input Functions Using Gradient Echo: A Simulation Study

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Introduction

Absolute blood flow and blood volume measurements using perfusion weighted MRI (PWI) require an accurately measured arterial input function (AIF). Due to limited spatial resolution of MR images, AIF voxels cannot be placed completely within a feeding artery. We present a two-compartment model of an AIF voxel including the relaxation properties of blood and tissue. The purpose of this study is to analyze the shape of partial volumed (PV) AIF signals and quantify the impact of partial volume effects (PVE) on the quantitative perfusion metrics given known relaxivity properties of tissue and blood (1,2,3). Our study extends earlier work to model PV AIFs by including the effects of the contrast agent (CA) bolus passage through surrounding tissue (1,4,5). We find that the tissue contribution broadens and introduces fluctuations in the AIF. Furthermore, PVE bias perfusion metrics in a nonlinear fashion, compromising quantitative perfusion estimates and profoundly effecting local AIF selection, (6).

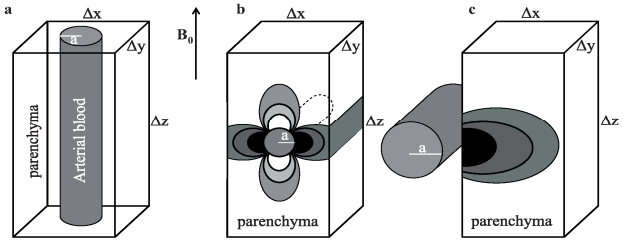


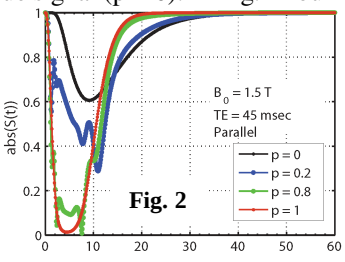
Fig. 1. The three AIF voxel models V_{para} artery parallel to B_0, V_{perp} artery perpendicular to $B_0$and V_{adj} voxels placed adjacent to artery.

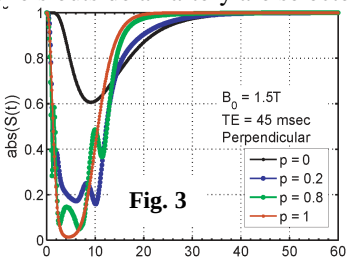
Methods

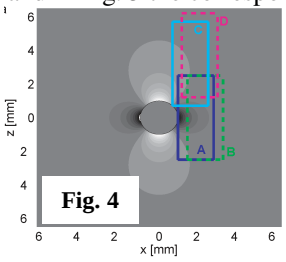
The AIF voxel is modeled with the artery as a long cylinder centrally placed occupying a volume fraction *p* of the voxel, Fig. 1. For a given input bolus of CA with a concentration *c*(*t*), the blood signal is calculated using the nonlinear relaxation effect of CA found in *in vitro* experiments (1,2). The CA bolus is simulated as a gamma variate function with peak concentration 8 mM. The tissue concentration of CA is calculated from *c*(*t*) and an exponential residue function with a delay of 0.5sec, using the parameters for brain grey matter and gradient echo measurement with B_0 = 1.5/3.0 T, T_E = 45/30 msec and T_R = 1.5 sec (3,7). For more details see (6).

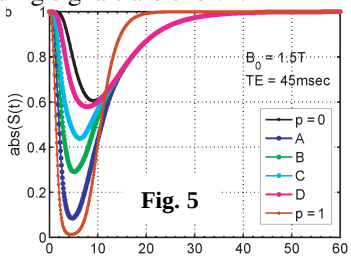
Results

In Fig. 2 and 3 noise free AIF voxel signals are shown for different partial volume together with the pure blood signal (p = 1) and pure tissue signal (p = 0). In Fig. 4 four voxels outside an artery are selected and in Fig. 5 the corresponding signals are shown.









Discussion & Conclusion

The main effect across realistic vascular geometries is that PV AIFs are broadened or display interference fluctuations compared to the true AIF. The fluctuations resemble signal variations typically ascribed to noise in AIF searches. Moreover, late fluctuations in the magnitude signal are observed to coincide with the typical arrival time of the second pass of the CA bolus, modulating its timing and amplitude, Fig. 2 and 3. The main conclusions are subdivided into five points: **(i)** For quantitative PWI, both shape and amplitude of the AIF are crucial. Signals from V_{perp} have approximately identical amplitudes Fig. 3, whereas signals from V_{para} display amplitudes that to some extent reflect the degree of PV, Fig. 2. Amplitude of AIFs from V_{adj} may vary extensively depending on position, Fig. 5. **(ii)** In practical AIF selection procedures (manual or automated) our study suggests that signals from V_{para} with high PV are easily excluded due to their lower signal amplitude. We speculate that experimental noise, sparse sampling and averaging of several voxel signals into one AIF will tend to mask fluctuations in the AIFs of low PV, providing seemingly appropriate (smooth) curves for perfusion analysis. Duhamel *et al.* (5) suggested the use of signals from V_{adj}. Our study extends their findings by demonstrating the further signal broadening resulting from the bolus passage in tissue, making these curves less appropriate for AIF selection. **(iii)** Automated AIF selection algorithms identifies voxels with 'arterial' signal characteristics such as (a) smoothness (b) maximal signal drop above noise level (c) large area under the curve (8,9,10). Especially the first two selection criteria favor signals from V_{adj}. We speculate that optimal AIF selection algorithms should include criteria for bolus width, reducing the bias from the subpopulation of the voxels that experience most broadening. **(iv)** PVE bias perfusion metrics in a nonlinear fashion (6). Measuring the AIF in V_{para} with low PV of tissue, the perfusion metrics are close to the true parameters. For typical voxel sizes this corresponds to arteries with radius above 1 mm. **(v)** Reduction of TE removes most of the fluctuations in the PV AIFs and reduces AIF broadening due to smaller tissue signal, (6). These observations support the use of multiple echo data acquisition schemes for reducing PVE, see e.g. (11).

References: (1) van Osch et al., MRM 49:1067,2003. (2) Akbudak et al., In Syllabus of ISMRM workshop on Quantitative Cerebral Perfusion Imaging Using MRI,2004. (3) Kjølby et al., MRM 56:187,2006. (4) Chen et al., JMRI 22:390,2005. (5) Duhamel et al., MRM, 55:514,2006 (6) Kjølby et al., accepted in MRM (7) Kiselev, MRM 46:1113,2001. (8) Murase et al., JMRI: 13:797,2001 (9) Calamante et al., MRM 52:789, 2004 (10) Mouridsen et al., MRM 55:524,2006. (11) Newbould et al.,MRM 58:70,2007