Improved CBF Quantification with Flow-adaptive Model Function for Multiphase PCASL – A Monte Carlo Simulation Study

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Purpose: Multiphase PCASL (MPPCASL) is a PCASL technique that is used for mitigating the tagging efficiency loss resulting from off-resonance fields and gradient imperfections at the labeling plane [1]. Instead of acquiring the ASL data at two RF phase offsets as in conventional PCASL (tag/control), the signal from multiple phase offsets is acquired on a per voxel basis and then fit to a model function in order to estimate of CBF. In the original implementation, a modified Fermi function was used for model fitting, whose parameters were chosen to yield the best fit with the inversion response curve at an arterial velocity of 30 cm/s. Because the shape of the curve is dependent on the velocity of flowing blood, the Fermi function may not yield the best estimate of perfusion if the blood passing through the labeling plane deviates from this velocity. In this study, we propose an alternate flow-adaptive function, which adjusts its shape to the experimental response curve for more accurate estimates of CBF. We used Monte Carlo simulations to quantitatively evaluate the accuracy of the proposed fitting method relative to the original implementation by generating simulated experimental signals with random noise for the full range of velocities relevant for human perfusion study.

Methods: The processing steps of this study are summarized in Fig. 1. First, Bloch simulations were used to generate inversion response curves as a function of RF phase offsets (Fig. 1A) for the velocity range of 10 cm/s to 60 cm/s with a step size of 1cm/s. Fig 1A was then used to generate the simulated "experimental" data for an 8-phase MPPCASL scan with the addition of Gaussian noise to achieve SNRs of 5, 15, 30, and 50 for the mean perfusion weighted image (Fig. 1B). For each "experimental" data set, 64 repetitions were used to match the parameters of a typical whole-brain PCASL scan. Each simulation for a given SNR and flow velocity was repeated 100 times, with each simulation generating an estimated ASL signal that was fit using both the original fitting method and the proposed adaptive fitting method (Fig. 1C). Note that the latter generates a velocity estimate in addition to the original CBF estimate. That is, the adaptive fitting approach fits the "experimental" data to each of the Bloch simulated responses shown in Fig 1A, and selects the one with the best fit to the data (in the least squares sense) as the fitting function.

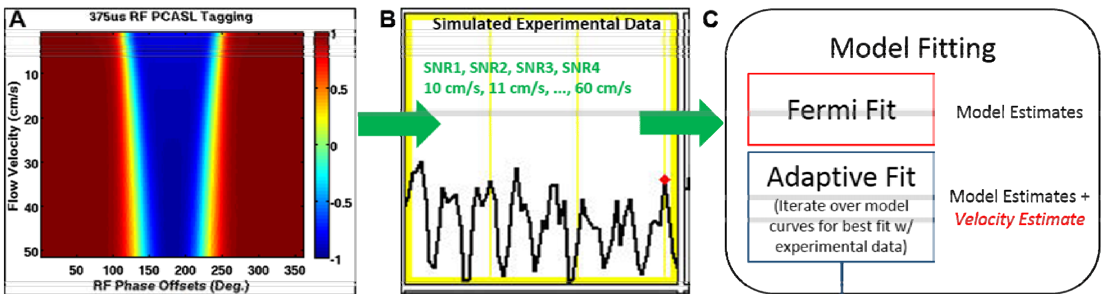
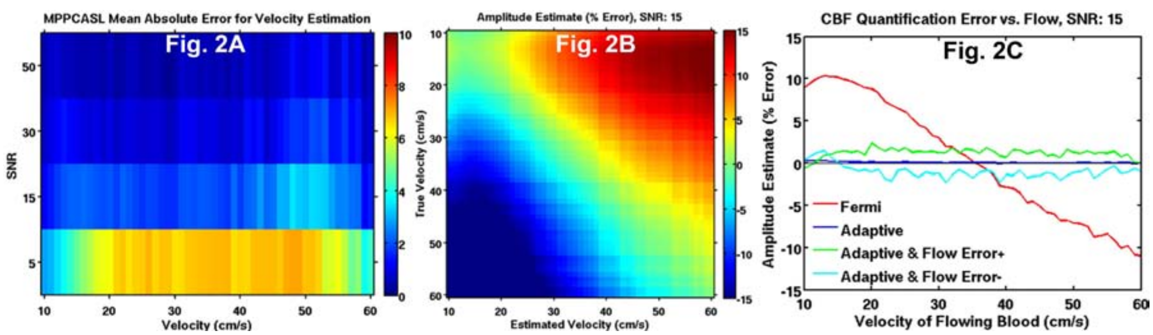


Fig. 1



Results & Discussion: Figure 2A shows the expected mean absolute error for the velocity estimates from the proposed adaptive fitting approach. For SNRs of 15 and greater, the velocity estimation errors of the proposed method are less than 3.5 cm/s. Figure 2B shows the expected percent error in CBF estimates when the assumed model velocity deviates from the velocity used to generate the "experimental data" for SNR = 15. This SNR was chosen for demonstration since the in vivo average SNR (e.g. signal averaged over a vascular territory) was determined to be 15.5 (n=6) based on a previous PCASL study [2]. Fig 2C shows the expected CBF quantification error for both of the fitting methods. The blue line corresponds to the performance of the new fitting method when the perfect velocity estimate is assumed. The curves in green and cyan show the accuracy of CBF estimates when the positive and negative velocity estimation errors (i.e. from Fig. 2A) are assumed. While the original fitting approach performs comparably well for the velocity range between 30 and 40 cm/s, the quantification error increases rapidly outside this range.

Conclusion: This study demonstrates that the accuracy of CBF measures can be improved by using the flow-adaptive curve fitting approach with MPPCASL. In addition, this method offers a means to estimate the velocities in the feeding vessels.

References: [1] Jung, et al. MRM 64:799-810, 2010. [2] Shin et al. MRM 68:1135-1144, 2012.