Modeling Flow Dispersion in Pseudocontinuous Arterial Spin Labeling and its Application in Moyamoya Disease Patients

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INTRODUCTION

Use of multiple delays in arterial spin labeling (ASL) [1] is a promising method to correct for error due to long arterial transit time in the measurement of cerebral blood flow (CBF). In this method, ASL signal may be measured when the bolus of labeled blood partially arrives at the imaging region with short delays. While the effect of flow dispersion may be minimal in single-delay ASL with an inversion delay longer than transit time, it may be critical in multi-delay ASL where the amount of labeled blood that partially arrives can be dependent on the dispersion of blood flow. In this work we model the effect of dispersion in pseudocontinuous ASL (PCASL) and demonstrate improved ASL signal data fitting in Moyamoya disease patients who typically have long arterial transit times.

METHODS

Subjects: Twelve consecutive patients (age 50 ± 17 years, 8 women, 4 men) with Moyamoya disease were recruited from those undergoing preoperative assessment for possible external-to-internal carotid artery bypass surgery. Each patient provided informed consent under local IRB guidelines.

Experimental Setup: Multi-delay PCASL was performed using five different post-labeling delays (PLD) of 700, 1275, 1850, 2425, and 3000 ms, each with 2-sec labeling duration (LD), and whole brain images were acquired using fast-spin-echo 3D stack of spiral acquisition with spatial resolution of 5.9 x 5.9 x 5 mm^3 over FOV = 220 x 220 x 160 mm^3. Scan time was 3:36 min. All scans were performed on a GE MR750 3.0 T.

Modeling: We modified the ASL signal equation from general kinetic model [2] to the following;

$$\Delta M(t) = 2M_{0b} \cdot c(t) * VTF(t) * m(t)$$

where M_{ob} is the equilibrium magnetization of arterial blood, and m(t) is magnetization relaxation function ($m(t)=\exp(-t/T_{1b})$). Unlike the original kinetic model, c(t) is the normalized arterial concentration at the labeling location, not imaging location (c(t) = 1 for $0 \le t < LD$, 0 elsewhere). VTF(t) is a vascular transport function and corresponds to the impulse response function with arterial blood signal at the labeling location as an input and dispersed and delayed arterial blood signal at the imaging location as an output. We modeled VTF(t) as a Gaussian function [3] with the mean of transit time and standard deviation of σ = K x TT where K is a consistent value within each subject and TT is the transit time for each voxel. In our model, the standard deviation of TT was proportional to TT based on previous findings [4-5].

Image analysis: K was varied from 0 to 1.5 (unitless) for each subject. For each value of K, transit times were calculated using the relationship between ASL-signal-weighted PLD and transit time, and CBF was calculated based on the estimated transit time [1]. Optimal K was found such that the mean squared error (MSE) of fitting is minimized. For segmental analysis, peripheral regions of brain cortex with 2 cm thickness were automatically delineated and divided into six segments for each slice, corresponding to the territories of left/right anterior/middle/posterior cerebral arteries.

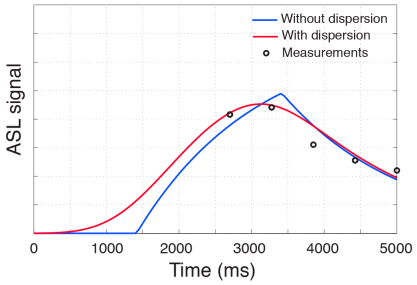

Figure 1. *Example of ASL signal curve fitted to the measured ASL signal with and without dispersion in the model.*

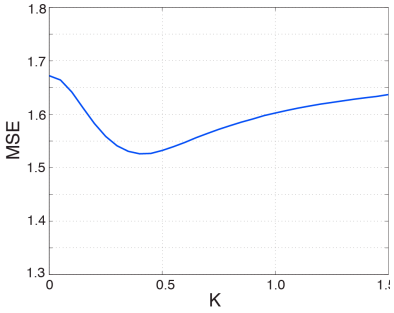

Figure 2. *Mean squared error of ASL data fitting can be minimized with optimal value of K, a global constant that determines dispersion in each subject.*

RESULTS

Figure 1 shows ASL signal model fitted to the measured ASL signal with and without dispersion for an example voxel. Figure 2 demonstrates the MSE as a function of K for a representative patient. In twelve patients, optimal K was found to be 0.30 ± 0.23, and the MSE was reduced by 4 ± 4% with optimal K compared to initial MSE without dispersion. Average CBF of the whole brain was 45 ± 10 and 43 ± 11 ml/100 g/min with and without dispersion, respectively. Average transit time was 1492 ± 308 and 1549 ± 262 ms with and without dispersion. Figure 3 demonstrates that reduction in MSE (i.e. improvement of fitting) increases for longer transit times. Figure 4 displays CBF maps with and without dispersion included in the ASL signal model from a representative patient.

CONCLUSION

We demonstrated improved fitting of ASL signal curve to the ASL measurement using a dispersion model of Gaussian function with standard deviation proportional to transit time. Improved data fitting was achieved particularly for the regions with long transit times. Regional underestimation of CBF was observed without dispersion modeling, compared to CBF with dispersion.

REFERENCES

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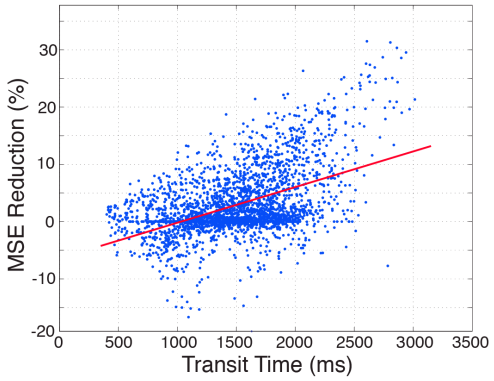

Figure 3. *Reduction in mean squared error (MSE) of ASL data fitting with optimal dispersion model as a function of transit time. Data points represent gray matter segments of all patients (six segments per each slice).*

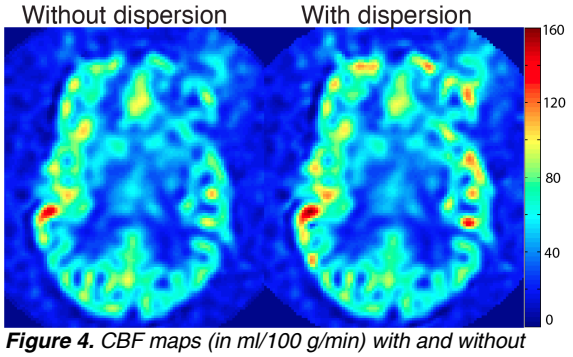

Figure 4. *CBF maps (in ml/100 g/min) with and without dispersion in the quantification model from one patient. CBF map without dispersion shows underestimation of CBF in the left anterior region.*