Modeling the Effect of Flow Dispersion in Continuous Arterial Spin Labeling

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Introduction: Arterial spin labeling (ASL) is capable of quantifying tissue perfusion non-invasively. Quantification of ASL perfusion measurements typically assumes that the flow from the labeling plane to the tissue is simple plug flow, i.e., all labeled blood requires the same transit time to the tissue. However, flow in the major arteries and branches into the brain is complicated, and may not be well approximated by simple plug flow. Flow dispersion models, including a Gaussian distribution (1,2) and a model based on fluid dynamics (3), have been used to describe the distribution of transit delay for pulsed labeling. For continuous labeling, only one model has been used to approximate flow dispersion (4). The use of dispersion models for quantification has not been widespread, in part because numerical methods are typically required to produce the signal curve. Here we propose the use of the gamma variate function without additional delay as a model distribution for perfusion quantification. The ASL signal from a gamma variate distribution can be readily expressed in terms of incomplete Gamma functions; a function that is readily available in most analysis environments, including MATLAB and IDL. The model was fit to experimental CASL data to validate the flow dispersion curve shape and estimate flow dispersion in the human brain.

Theory: A gamma variate distribution of transit times is assumed. This distribution is of the form $p(\tau) = \frac{1}{\eta^\gamma \Gamma(\gamma)} \exp\left(-\frac{\tau}{\eta}\right)$ where $\gamma$, the dispersion model, but not the typical model. Typical fitting quality is shown in Fig. 2. The curve from the dispersion model is smoother, unlike the standard model with the physiologically unlikely peak shape. The dispersion model gives similar fit quality for the red voxel (Fig. 2f, $m=287$ and $\eta=0.0039$) and clearly better fit for the green voxel (Fig. 2h, $m=2.79$ and $\eta=0.42$) compared with the standard model. Indeed, the dispersion model will converge to the typical model when $m$ goes to infinity and $\eta$ goes to zero. This indicates that the transit delay of the red voxel is close to plug flow but not the green pixel. The signals in the spatial locations with large flow dispersion will be better described by the dispersion model, but not by the standard model. Therefore, The R square dispersion map reflects the degree of flow dispersion. It can be seen that deep gray matter regions have less dispersion and posterior regions have more, consistent with results reported with the PALS (10). The mean and standard deviation of transit time calculated from Eqs. [2] and [3] in the dispersion model are shown in Fig. 1b and Fig. 1g. The standard deviation of transit time is a quantitative measure of dispersion, which shows a similar distribution to the R square dispersion map. The histogram of fractional dispersion, defined as a ratio of the standard deviation to the mean of transit time, demonstrates that the overall fractional dispersion of gray matter voxels is approximately 0.2.