Optimized Design of MRF Scan Parameters for ASL Signal Acquisition

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Purpose: Arterial Spin Labeling (ASL) produces perfusion weighted images without injection of contrast agents. Multiple hemodynamic parameters can be estimated through the application of fingerprinting techniques to arterial spin labeling data. The purpose of this work is to design optimized scan parameters for acquiring MRF ASL signals using a Cramer-Rao Bound based approach, for a fixed scan duration of 240 seconds. This optimization improves precision in estimating relevant hemodynamic functions.

Methods: We consider various timing schemes for the label order and duration to design an optimized ASL sequence for the model described in [1]. We investigated determining the labeling durations as follows: (i) a Perlin function similar to that used in [1], (ii) a Perlin function with one pseudo-random point, and (iii) a quartic polynomial whose coefficients are constrained to [-1, 1]. In the first case, the only adjustment was a scaling to ensure the scan time is 240 s. For the second case, we optimized the labeling duration at the pseudo-random (PR) point. In the final case, we optimized the polynomial coefficients. We also optimized a time-reversed quartic polynomial with similar constraints. After optimization, we scaled the labeling schedule to ensure that all scans are 240 s long. Additionally, we investigated the effect of increasing the number of pseudo-random points in the Perlin noise function as well as the effects of randomized and strictly paired control and tag (label) scans. Our design cost function, inspired by [2], was based on a normalized Cramer-Rao Bound (CRB) that is calculated numerically, and is described as:

$$\psi(\nu) = Trace\left(W \cdot \frac{|I^{-1}(\theta;\nu)|^{\frac{1}{2}}}{N} \cdot W \right),$$

where $I^{-1}(\theta;\nu)$ is the inverse Fisher Information Matrix, the diagonal elements of which represent the minimum variances in the unbiased estimation of ASL signal parameters θ, and ν represents the set of labeling function parameters that we will optimize. W is a diagonal weighting matrix, N is a matrix that normalizes the standard deviation in parameter estimates and the division signifies the element-wise division of matrices. For calculating the Fisher Information matrix, we assume that the noise in the process is independent across all acquired frames, and distributed identically as a Gaussian random variable with zero mean and a standard deviation that is approximately 0.01 times the equilibrium magnetization in an imaging voxel, as determined from preliminary scan data.

Name of Parameter	Perlin Noise (0 PR point, Cosine)		Perlin Noise (1 PR point, Cosine)		Polynomial Scheme		Polynomial Scheme (reversed)
	Random Ctrl-Tag	Paired Ctrl-Tag	Random Ctrl-Tag	Paired Ctrl-Tag	Random Ctrl-Tag	Paired Ctrl-Tag	Random Ctrl-Tag
CBVa	11.8	14.0	6.6	6.7	6.8	7.0	6.8
BAT : Tissue	6.8	6.2	8.2	6.6	8.0	6.3	8.2
BAT : Artery	8.3	9.1	8.1	8.0	9.1	8.4	9.2
Flow	36.1	42.2	27.9	33.6	25.8	30.1	25.4
Pass Through Artery Transit Time	12.5	11.5	10.1	8.9	9.6	9.7	9.7

Table 1: Optimized normalized minimum standard deviation (in %) of parameter estimates around central parameter values, obtained from 1000 frames and scan times of 240 seconds

Results/Discussion: Optimizing over our choice of labeling functions revealed that the optimized quartic polynomial significantly improved the precision of estimating ASL parameters like Bolus Arrival Time (BAT) for tissue and artery, Flow, Cerebral Blood Volume fraction (CBVa), etc., over other schemes as depicted in Table 1. As expected, randomized control-tag protocols performed consistently better than strictly paired ones. Increasing the number of PR points in the Perlin noise function beyond one did not improve the objective function, as can be seen in Figure 1. Figures 2(a)-(c) depict optimized labeling duration for different schemes.

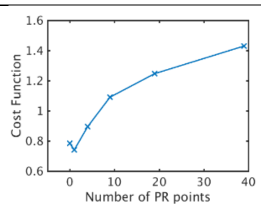

Figure 1: Cost function values across number of PR points in Perlin Function.

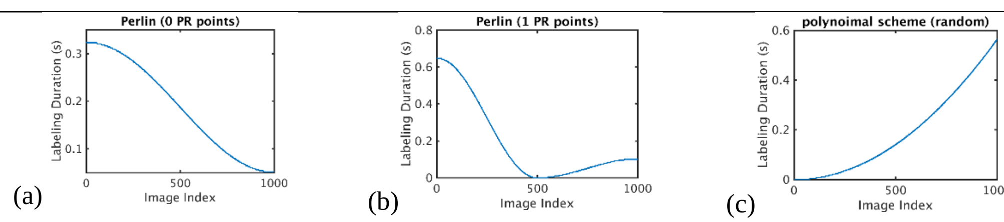

Figure 2: **(a)** Perlin function with 0 PR points. **(b)** Optimized Perlin function with 0 PR points. **(c)** Optimized Polynomial Scheme

Conclusion: We conclude that proper optimization of scanning parameters for ASL signals, like labeling duration, using a metric like CRB that is firmly rooted in Statistical Inference theory, significantly improves the maximum possible precision of parameter estimates. However, even the optimized normalized standard deviation of flow at 25% is undesirably large, indicating the need for further optimization of acquisition parameters.

References: [1] P Su, et al. MRM, 2017 (early view). [2] G Nataraj, et al. IEEE Trans. on Med. Imag.,2017

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