# Comparison of Cerebral Blood Flow and Arterial Transit Time Estimation Methods using Monte-Carlo Simulation

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**Target Audience:** This information is intended for physicists, neuroscientists, and radiologists interested in cerebral blood flow (CBF) measurement.

**Purpose:** The arterial transit time (ATT) in arterial spin labeling (ASL) is defined as the time required for the blood to travel from the labeling location to its ultimate location of exchange. To allow the labeled blood to travel to the exchange location, a post-labeling delay (PLD) is inserted between the application of the label and the acquisition of the image. The selection of a single optimum PLD is difficult because the ATT varies widely across the brain, between patients, and can change with pathology. Simultaneous estimation of ATT and CBF can provide more accurate CBF estimates without sensitivity to ATT. In addition, an ATT map may be helpful on its own as a tool for diagnosis of cerebrovascular abnormality, such as identifying ischemic penumbra and infarction. The most basic method of mapping ATT is to collect many ASL images with different PLDs, which is very time consuming and, therefore, not practical. Multiple time efficient methods have been proposed for simultaneous ATT and CBF estimation. This work examines the tradeoffs of three major methods: Variable TR method: shortened TR with pre-saturations according to PLD (1), Hadamard encoded ASL: subdivided label into multiple sub-boluses, later decoded into several images with different effective PLDs (2), and Look-Locker acquisition: repeated acquisition of an imaging volume with one label application (3).

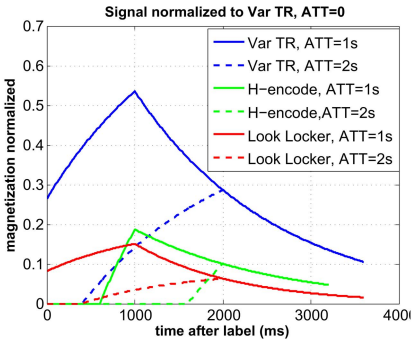


***Figure 1.*** *Normalized perfusion signal from a single tag/control pair over time for three methods with ATT=1s (solid line) and 2s (dash line)*

**Methods:** Simulations were performed in order to compare the ATT and CBF estimation efficiencies of each method using continuous or pseudo-continuous labeling. Signal from a single tag/control pair was generated for each method according to the general hemodynamic model (4) (see **Fig 1**). The $T_1$ of blood and gray matter were assumed to be 1600ms. Zero-mean Gaussian noise was added to the simulated signal at all time points independently. Standard deviations of the noise were chosen to set the SNR of a single tag/control difference signal at 1400ms ATT with 1600ms bolus duration to 2 and 4. The signals were averaged according to the number of averages feasible in a given scan time (5 min.) (see **Table 1**). The imaging time was assumed to be 400 ms for all methods. The PLD for Variable TR ranged from 0 to 3200ms. There were eight 400ms sub-boluses used in the Hadamard encoding method. A train of 9 image volumes were collected per label with a flip angle of 25° in the Look-Locker method (3). All other simulation parameters are summarized in **Table 1**. Monte Carlo simulations were performed with 1000 iterations.

***Table 1.*** *Summary of ASL parameters for simulation*

| | Look Locker | Hadamard Encoding | Variable TR |
|---|---|---|---|
| TR (ms) | 5200 | 3600 | 3600 (avg) |
| Bolus Duration (ms) | 1600 | 400 | 1600 |
| Flip Angle (deg) | 25 | 90 | 90 |
| PLD increment (ms) | 400 | 400 | 400 |
| Averages in 5 min | 27 | 8 | 4 |

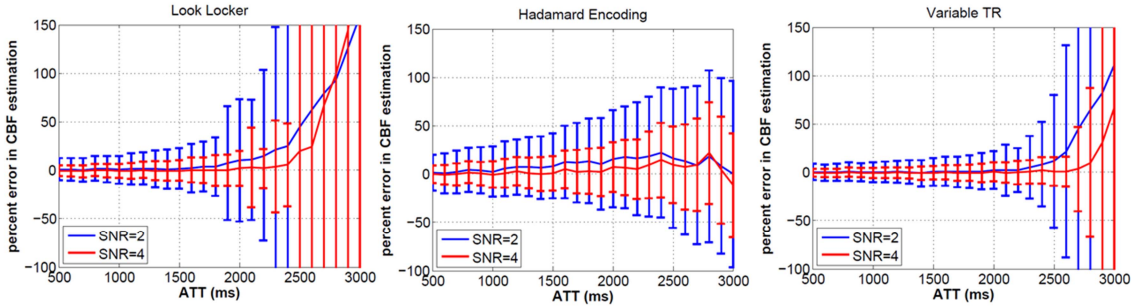


***Figure 2.*** *Mean percent error in the CBF estimation for ATT ranging from 500ms to 3000ms. The error bars indicate the standard deviations of the estimations.*

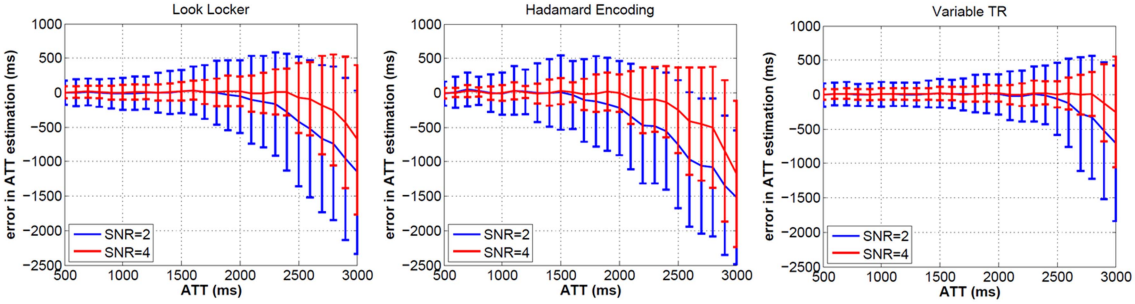


***Figure 3.*** *Mean error in the ATT estimation for ATT ranging from 500ms to 3000ms. The error bars indicate the standard deviations of the estimations.*

**Results:** **Fig 2** shows the percent error in the CBF estimation. The variable TR method had the lowest simulated error in CBF estimation for ATT values ranging 500ms to 2500ms and the Hadamard encoding method showed lowest errors for ATT longer than 2500ms. The error between ATT estimates and true values is shown in **Fig 3**. The variable TR method showed lowest errors in the experimental range.

**Discussions:** For ATT values longer than 2500ms, which is often the case for white matter, none of the methods investigated demonstrated acceptable levels of error (> 100% in CBF estimate with SNR of 2). Even though the variable TR method had the lower error, due principally to the higher signal amplitude (see **Fig 1**), the Look-Locker method may be more advantageous in that is has low sensitivity to motion due to more signal averaging. A possible reason that the Hadamard encoding method showed lowest errors in CBF for long ATT (>2500ms) may be that the shorter bolus duration allowed for better fitting of the signal.

**References:** (1) Lu K, Liu TT, Jung Y. ISMRM 2010: 1769. (2) Dai W, Shankaranayanan A, Alsop DC. MRM [epub ahead of print]. (3) Guther M, Bock M, Scad LR. MRM 2001; 46(5):975-984. (4) Buxton et al. MRM 1998;40(3):383-396