Multiresolution strategy to estimate arterial transit time and cerebral blood flow maps in rhesus monkeys

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Introduction Cerebral blood flow (CBF) calculation using the arterial spin labeling technique generally does not take into account regional difference in arterial transit time (ATT). A single ATT value taken from other studies is often used for the entire brain. It has been suggested that ATT needs to be taken into account to obtain quantitatively accurate CBF image [1]. ATT maps can in principle be estimated from cASL measurements at different post-labeling delays. However, pixel-by-pixel fitting of these data is noisy and conventional algorithms are inadequate.

In this study, we employed multiresolution strategy to estimate ATT and CBF pixel by pixel from cASL measurements with different post-labeling delays. Multiresolution approach is widely employed in image analysis to improve image quality [2]. Multiresolution strategy consists of constructing a multiresolution pyramid dataset of different re-sampled spatial resolution from coarse to fine. Parameters are first obtained by fitting the re-sampled coarse resolution data which has higher SNR. These initial parameters provide as priori knowledge and initial constraints for fitting at the next finer resolution. This procedure is repeated until the original resolution is reached. CBF and ATT maps were obtained simultaneously from the fitting of the CBF equation.

Methods Rhesus monkeys were placed in the sphinx position and immobilized with the custom-built holder under ~1% isoflurane. End-tidal CO2, inhaled CO_2, O_2 saturation, heart rate, respiration rate, and rectal temperature were monitored continuously and regulated.

CBF was measured using the cASL technique with a separate neck coil for arterial spin labeling on a 3.0T Siemens Trio as described elsewhere [3]. MRI parameters were: single-shot gradient-echo EPI with 1.5 isotropic resolutions, TR = 5.0 s, labeling duration = 2.0 s, 16 1.5-mm slices with 33% gap between slices, TE = 31 ms, matrix = 64 × 64, FOV = 9.6 × 9.6 cm, and post-labeling delays of 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 0.9, 1.1, 1.3, 1.7 s (first slice imaged). The post-labeling delay for subsequent slices was accounted for with known acquisition time per slice of 67 ms.

The multiresolution strategy consists of the construction of the multiresolution pyramid dataset at different resolution level from coarse to fine. At each level, multiple post-labeling delays data were fitted using the model proposed by Alsop and Detre [4],

$$\Delta M = \frac{2\alpha M_b^0 f}{\lambda}\left\{T_{1tis} * \exp(\frac{-\delta}{T_{1\alpha}}) * \exp(\frac{\min(\delta - w,0)}{T_{1tis}}) + T_{1\alpha}\left[\exp(\frac{\min(\delta_\alpha - w,0) - \delta_\alpha}{T_{1\alpha}}) - \exp(\frac{\min(\delta - w,0) - \delta}{T_{1\alpha}}\right]\right\}$$

where M_b^o is the equilibrium magnetization, α is the labeling efficiency, f is the CBF in ml/g/s. λ is the brain-blood partition coefficient, T_{1tis} is the tissue T1, and T_{1a} is the blood T1. δ_a is the transit time from the labeling plane to the arterial compartment, δ is the transit time from the labeling plane to the slice imaged, w is the post-labeling-delay. λ is 0.9, α is 92%, T_1 map were obtained using invervsion recovery EPI measurements.

Our pyramid consists of three different layers: 16x16, 32x32, and 64x64. Each layer was generated using the moving average of neighboring pixels. The fitted parameters obtained at the coarse level were used as the prior knowledge and initial estimation for fitting at the next finer level to generate maps. CBF and ATT in gray matter (GM) and white matter (WM) were quantified for comparison.

Results The resultant CBF, ATT and R_1 maps are shown in **Fig 1**. CBF and ATT maps were heterogeneous. GM showed higher CBF and shorter ATT in the GM compared to WM. CBF values in the GM and WM were 110 ± 15 and 57±13 ml/100g/min, respectively. The ATT values in the GM and WM were 450 ± 250ms and 870 ± 310ms, respectively.

Discussion & Conclusion Multiresolution strategy fitting provides efficient and accurate estimates of the multiparametric modeling of data with inherently low SNR. Quantitative CBF and ATT maps in the anesthetized rhesus monkeys were derived. CBF values obtained with multiresolution strategy are consistent with those using a single ATT for the entire brain. Note that CBF values reported herein are high compared to those in awake humans. This is because the anesthetic (isoflurane) used is a known vasodilator, as amply demonstrated in rats [5,6]. ATT values in monkeys are shorter than those reported in awake humans (590ms to 950ms in GM [7]), likely due to size differences between the two species. ATT maps have not been previously reported in monkeys. In conclusion, this approach has strong implications in accurate CBF quantification and stroke imaging where tracer arrival time is significantly delayed.

References: [1] Buxton R et al, MRM, 1997; Yang Y et al, MRM, 2000. [2] Rosenfeld A, Multiresolution image processing and analysis, Springer-Verlag, 1984. [3] Zhang X, et al, Neuroimage, 2006 [4] Alsop et al, JCBFM, 1996. [5] Sicard & Duong, NeuroImage 25:850, 2005. [6] Ibaraki M et al. J Cereb Blood Flow Metab 25:378 2005. [7] Gonzalez-At et al, MRM, 2000.

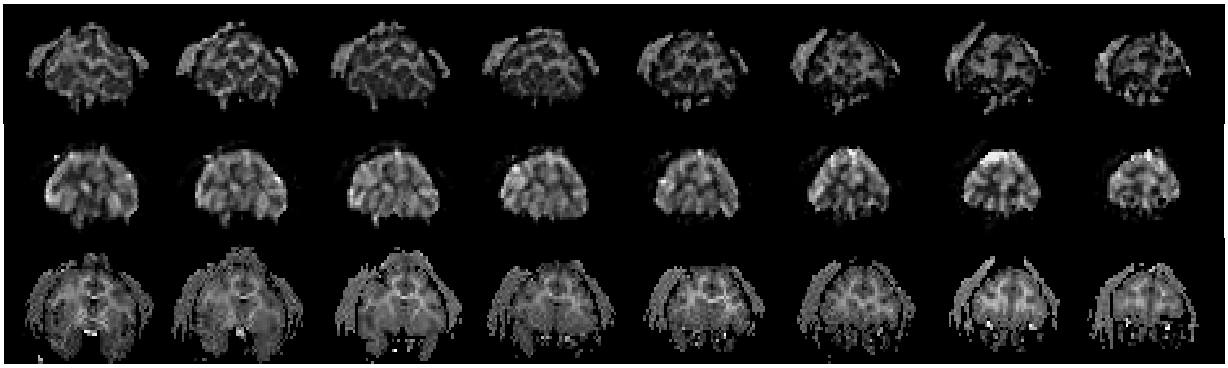

Fig 1. ATT (top), CBF (middle), and R_1 (bottom, 1/T1) maps of an anesthetized rhesus monkey at 1.5 mm isotropic resolution.