Comparison of Arterial Transit Times Estimated Using Arterial Spin Labeling

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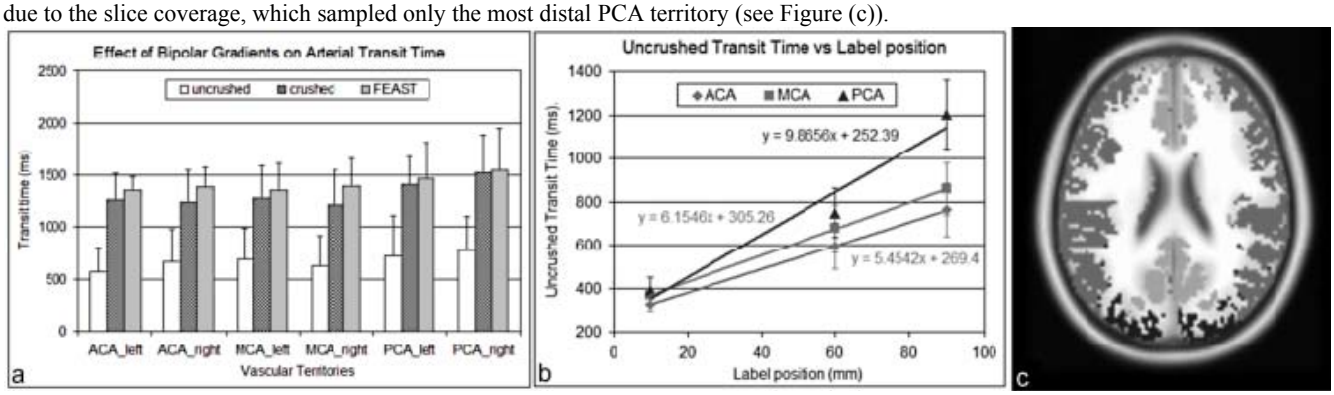
Introduction Arterial transit time is a parameter unique to arterial spin labeling (ASL), and it refers to the time needed for labeled spins to travel from the label region to the imaging region. Traditional ASL experiments focus on cerebral blood flow quantification and therefore do not provide transit time information. However, knowledge of transit time can aid detection of collateral flow in clinical situations[1], as well as better understanding of hemodynamic changes during functional activation[2]. Recently, two efficient transit time mapping techniques: Look-Locker ASL and flow encoding arterial spin tagging (FEAST) have been introduced. In this study, we investigate the effect of flow crushing bipolar gradients and labeling position on the transit time estimates of both methods.

Methods Five healthy subjects (age 25±8, 3F/2M) were scanned in a 3.0T whole body MR scanner (Siemens TIM Trio, Erlangen, Germany) with an eight-channel receive-only head coil and body coil transmission. All subjects were scanned with LL-FAIR[3], LL-pseudocontinuous ASL (LL-pCASL) and pCASL-FEAST[4]. Ten inversion times (TI) ranging from 100ms (TI_1) to 2800ms with TI interval (TI_2)=300ms were acquired for the LL scans. Gradient echo-planar imaging was used for image acquisition for all three sequences with the following parameters: FA=90° (FEAST)/25° (LL), TE/TR=40ms/3.5s (LL-FAIR)/4s (FEAST and LL-pCASL), 50 pairs of control/tag, 4 axial slices (5mm thick, 2.5mm gap). Labeling duration and postlabeling delay for pCASL-FEAST were 1.5s and 1s respectively. The LL-ASL scans were repeated with bipolar gradients (Venc= 8mm/s, b=9.3 s/mm^2) to suppress vascular signal, providing an estimate of microvascular transit time, while the uncrushed scans measured arterial transit time. Both LL-pCASL and FEAST were repeated at labeling offsets of 60mm and 90mm from the center of the imaging region. LL-FAIR was implemented with a 10mm gap between labeling and imaging regions.

Mean difference maps between control and tag images were calculated in Matlab and used for model fitting. The LL-FAIR and LL-pCASL data were fitted with either the modified General Kinetic Model [ref] or the two-compartment model [ref] to obtain transit time estimates. FEAST transit time was extracted from the ratio of the uncrushed and crushed difference maps. All images were normalized to MNI templates to facilitate extraction of vascular territory regions of interest (ROI), including the anterior (ACA), middle (MCA) and posterior cerebral arteries (PCA).

Results Figure (a) shows the effect of crusher gradients on the estimated arterial transit time for the 60mm label offset LL-pCASL data. The crushed transit times were on average 650ms longer than the uncrushed transit times. FEAST transit times were in excellent agreement with the LL-pCASL crushed transit times, which was expected since both were designed to measure the same microvascular transit time. The same trend was observed for the 90mm label offset data (not shown). Figure (b) shows the effect of label position on the uncrushed transit time estimates, combined over hemispheres. The LL-FAIR transit time was approximately 720ms shorter than LL-pCASL with 90mm label offset, indicating this is the time necessary for labeled spins to travel 80mm for the anatomical region imaged in this study. Both ACA and MCA data were well fitted with a linear model, the slope of which has units of velocity and were 16.2 cm/s (ACA) and 18.3 cm/s (MCA) respectively. PCA data was clearly nonlinear, likely due to the slice coverage, which sampled only the most distal PCA territory (see Figure (c)).



Discussion In the current study, we compared two methods for efficient transit time mapping: FEAST and LL-ASL, and investigated the effects of labeling location and bipolar gradients on the transit time estimates. The uncrushed transit time of LL-FAIR was 720 ms shorter than LL-pCASL with 90mm label offset, reflecting a labeling position discrepancy of 80mm. Both the ACA and MCA data showed linear relationship with label position. The inverse of the best-fit line provides an estimate of the mean blood velocity from the labeling region to the imaging region. The PCA data was nonlinear, possibly due to insufficient coverage of PCA territory in the current study, as well as vessel tortuosity. Interestingly, the y-intercept of the linear model was ~250ms, suggesting there is a nonzero transit time for labeled spins to traverse the complicated vascular tree before reaching the imaged voxel, even when the label location is placed adjacent to the imaging region. In this regard, velocity-selective ASL[5] may be the only option to avoid transit delay as labeling is applied within the voxel.

Our results also demonstrate that the LL-ASL sequence can be tailored to be sensitive to various transit times. Without bipolar gradients, LL-ASL is sensitive to arterial transit time, whereas the addition of bipolar gradients attenuates signal in large arteries, making the sequence sensitive to microvascular transit time. Our data showed a discrepancy of approximate 650ms between the uncrushed and crushed transit times, which represents the time needed for labeled spins to travel from arteries to capillaries, likely related to oxygen exchange at the capillary bed, which is limited by oxygen transport via blood flow[6]. FEAST, on the other hand, cannot provide macrovascular transit time explicitly, even though its microvascular transit time estimate includes contribution from macrovasculature. Since most common forms of cerebrovascular disorders are due to large artery stenoses, uncrushed LL-ASL may be more clinically relevant than the crushed alternative or FEAST.

References

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