Time-resolved Non-contrast Enhanced 4-D Dynamic MRA using Multi-bolus TrueFISP based Spin Tagging with Alternating Radiofrequency (True-STAR)

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Introduction: Arterial spin labeling (ASL) techniques have been recently applied for MR angiography (MRA). Pseudo-continuous ASL (pCASL) is able to achieve whole brain MRA with sub-millimeter 3D isotropic resolution [1]. The drawbacks for pCASL based MRA, however, include relatively long labeling durations (a few seconds) and high levels of RF specific absorption ratio (SAR). Time-resolved 4D dynamic MRA (dMRA) has been introduced recently by combining pulse ASL (PASL) with a multi-phase segmented balanced SSFP sequence [2-3], which offers high spatiotemporal resolution for depicting the dynamic flow pattern through the vasculature. However, the SNR is relatively low and the labeled bolus only lasts 1-2 sec which limits the capability of dMRA for depicting draining veins in arteriovenous malformations (AVM) [4-5]. The purpose of this study is to introduce a new dMRA technique termed multi-bolus TrueFISP based Spin Tagging with Alternating Radiofrequency (TrueSTAR), by combining the benefits of PASL, including short RF duration and low SAR, and pCASL, including higher SNR and prolonged labeling bolus.

Pulse Sequence: The multi-bolus TrueSTAR technique utilizes a train of intermittent hyperbolic secant (HS) inversion pulses for spin labeling. It takes advantage of the phenomenon that the magnetization of balanced SSFP can be temporally stored along z-axis by applying an $\alpha/2$ pulse, while magnetization preparation (e.g. spin labeling) can be performed. The steady-state precession can then be resumed by applying another $\alpha/2$ pulse. Spin tagging was implemented using the STAR scheme. Each inversion pulse (except the first one) was sandwiched by 2 $\alpha/2$ pulses and interleaved by a number of phases of balanced SSFP acquisitions.

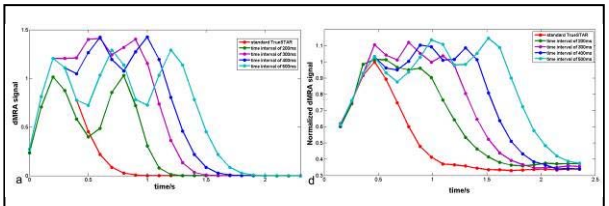

Figure1 Simulated labeled blood signal by standard (single) and three-bolus TrueSTAR with different time intervals at flow velocity of 20cm/s (Left), and the experimental dMRA time courses within arteries are shown in (Right).

Simulation: The temporal profile of labeled blood bolus can be described as a box-car function convoluted with a dispersion kernel. By incorporating T1 relaxation ($m(t)$), the signal of labeled bolus can be expressed as $M_a(t)=2M_{0b}m(t)W'(t)$, where $W'(t)$ is the temporal profile of labeled bolus with dispersion which can be described by the Gaussian dispersion model [6]. In the case of more than one tagging bolus, the interaction between two consecutive boluses was considered if the leading edge of the subsequent bolus occurs before the trailing edge of the preceding bolus. Single and three-bolus dMRA with different time intervals were simulated with a mean flow velocity of 20cm/s, according to the measured mean flow velocity of 21cm/s in internal carotid arteries from all the subjects using phase contrast MRI.

Experiments: All experiments were performed on a Siemens TIM Trio 3T scanner. Eight healthy volunteers (24.6±3.6yrs, 3males) participated in this study. Two experiments were conducted: Exp 1) Optimization of the imaging parameters for multi-bolus dMRA and validation of the simulation results. A three-bolus TrueSTAR sequence was implemented with the time interval of 210, 315, 420 and 525 ms between inversion pulses respectively. The tagging was applied to an 80mm slab inferior to the image slab with a 20mm gap. The rest parameters were: FOV=220×165 mm^2, resolution = 1×1×1.5 mm^3, rate-2 GRAPPA, a 3D slab of 40 slices with 1.5mm thickness, 22 phases from 150 to 2370ms with a step of 105ms were acquired within a total scan time of 7min. Exp 2) Comparison of optimized multi-bolus dMRA with standard single-bolus PASL and pCASL based dMRA. The phase interval of 4 (420ms) between inversion pulses was chosen for multi-bolus dMRA, with the rest parameters identical to the protocol used in Exp 1. For comparison, a standard single-bolus TrueSTAR sequence and pCASL based dMRA with a labeling duration of 300, 600 and 900ms were performed using closely matched imaging parameters. DMRA images were generated by complex subtraction between label and control acquisitions, and maximum intensity projection (MIP) images were generated for each phase along three directions (transverse, sagittal, coronal).

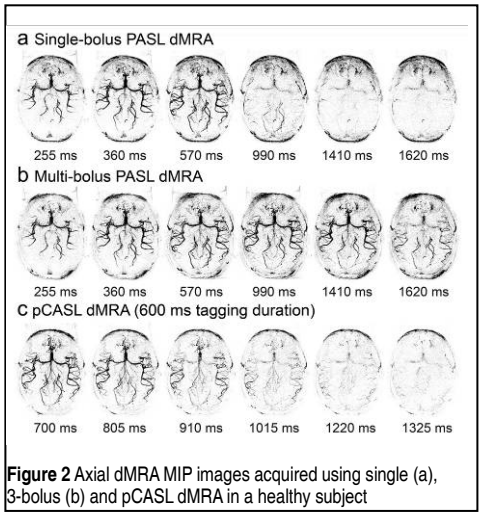

Figure 2 Axial dMRA MIP images acquired using single (a), 3-bolus (b) and pCASL dMRA in a healthy subject

Results:

As shown in Fig. 1, consistent results were obtained from simulation (Left) and experimental results (right). Compared to the standard single-bolus TrueSTAR, a prolonged bolus of labeled blood can be achieved using multi-bolus TrueSTAR. Based on both simulation and experimental results, the optimal bolus interval should be around 400ms to achieve a prolonged and continuous bolus of labeled blood in multi-bolus dMRA with a mean flow velocity of 20cm/s. Figure 2 shows the dynamic MRA MIP images using single (a), 3-bolus (b) PASL dMRA, and pCASL dMRA (c) with a labeling duration of 600ms. The full passage of labeled blood through the Circle of Willis and its main branches can be visualized using single and 3-bolus dMRA. However, the arterial inflow phases were missing in pCASL dMRA. Compared to single-bolus dMRA, a prolonged bolus with a relatively constant plateau was achieved using 3-bolus TrueSTAR with 16% increased SNR ($p<0.05$). Figure 3 shows the dMRA MIP images as well as collapsed MIP (cMIP) images using 4-bolus (a) and single-bolus (b) PASL dMRA. Improved delineation of the nidus and draining veins was achieved using multi-bolus TrueSTAR (SNR=41.2) compared to single-bolus TrueSTAR (SNR=34.4).

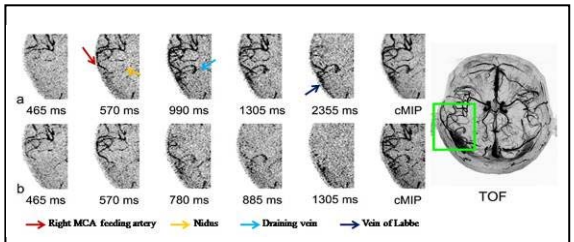

Figure 3. Representative temporal phases of axial dMRA MIP images and collapsed MIP image (cMIP) acquired using 4-bolus TrueSTAR (a) and standard TrueSTAR (b) from the AVM patient. TOF MRA MIP images after the injection of gadolinium contrast agent is shown on the right side.

Conclusion: By combining the benefits of pulsed and pCASL based dMRA, multi-bolus TrueSTAR can prolong and enhance the tagging bolus without sacrificing imaging speed or temporal resolution.

References:

[1]Robson, PM et al., Radiology 257(2):507-15, 2010. [2] Yan, L. et al., Radiology 256:270-9, 2010. [3] Bi, X., et al., MRM 2010; 63(3):835-841 [4] Xu, J. et al., JMRI 34:1199-205, 2011. [5] Yu, S., et al., MRI 2011; 30(6):869-77. [6] Hrabe, J., and Lewis, DP., et al., JMRI 2004; 167(1):49-55