Multi-Bolus Pulsed ASL for Improved Renal Perfusion Quantification

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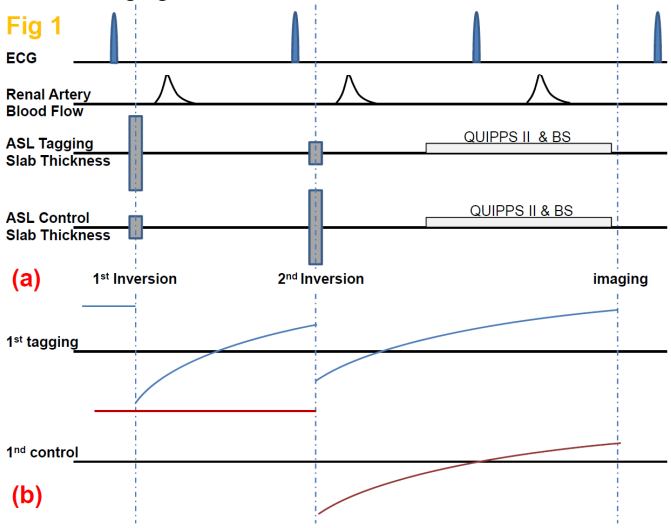
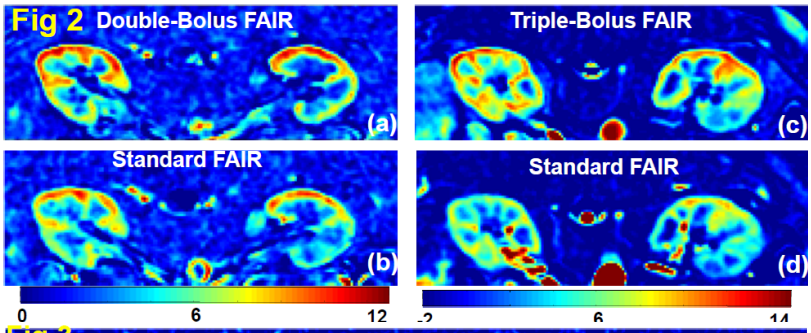
Introduction: Despite the fact that renal cortical blood flow rate is ~6 times of human brain perfusion, it remains a challenging to obtain reliable perfusion quantification with arterial spin labeling (ASL). Respiratory motion can generate severe imaging artifacts. Multiple breath-hold or controlled breathing strategies has been evaluated previously to improve the robustness of the quantification (1). Pulse ASL (PASL) (2) and pulsed continuous ASL (pCASL) (1) perfusion preparation with EPI, RARE or SSFP acquisition has been utilized in renal perfusion. Although pCASL can achieve up to 50% increase in SNR when compared to PASL in brain application (3), its intrinsic high SAR in abdominal MRI limits the adoption of SSFP-based image acquisition that has higher in SNR and less sensitive to non-uniform B0 field. In this study, the high pulsatile flow within the descending aorta was exploited to improve the sensitivity of renal PASL measurement by combining multiple ASL boluses that would help shorten imaging time.

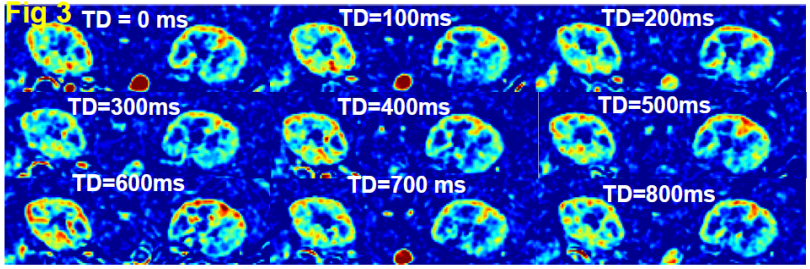
Methods: All experiments were performed on a 3T Siemens Trio scanner. Nine studies were performed on 4 healthy volunteers for this IRB approved study. It is known by MRI (4) or ultrasound technique that aorta blood flow and velocity at renal artery level is highly pulsatile. Blood velocity is significant only at ~1/3 of cardiac RR interval (from ~100 ms to ~400 ms after ECG trigger). Hence, continuous application of pCASL RF pulse train beyond that window has negligible effect. In a renal PASL study, due to fast renal arterial transit time (~150 ms (5)) and rapid aorta flow (peak velocity ~70- 100 cm/sec), the blood labeled in the descending aorta can be completely replenished by fresh blood within one RR interval. This allows for the possibility of generating multiple labeling boluses across multiple RR intervals for improved PASL sensitivity, which is equivalent as performing CASL without the related high SAR. **Fig 1a** shows the sequence diagram for augmented FAIR (6) implementation with double-bolus, while a triple-bolus approach is similar. During PASL tagging, non-selective (NS) inversion pulse (200-400 mm thickness) was applied immediately after the detection of ECG trigger signal. After approximately a RR delay (900 ms), a slice selective (SS) inversion pulse (20 mm thickness) was applied. The order for NS and SS inversion pulses were reversed during the ASL control. The combined TI was 2600ms (3800ms for a trio-bolus FAIR) with the interval between the last tagging pulse to imaging as 1700 ms. To improve robustness, background suppression (BS) scheme (7)was adopted by applying an extra non-selective inversion pulse between the last inversion and the imaging block. QUIPPS II was utilized (800ms saturation (TD) before imaging) for accurate perfusion quantification (8). True-FISP was used for single shot image acquisition: FOV of 300x225 mm^2, voxel of 1.6x1.6x6.0 mm^3; TE of 1.4ms; echo spacing of 3.3ms; flip angle of 70 degree.



Result & Discussion: **Fig. 1b** illustrates the time course of the spin evolution for the 1st labeling bolus (effect from BS pulse not illustrated). The spin evolution for the 2nd bolus is the same as a standard FAIR. Using Bloch equation simulation, double-bolus and triple-bolus FAIR scheme adopted in this study can achieve ~30% and ~50% improvement on perfusion signal (ΔM), respectively. **Fig. 2** shows the mean perfusion signal acquired with double-bolus (NEX=2, **Fig. 2a**) and triple-bolus (NEX=12, **Fig. 2c**) FAIR and the corresponding standard FAIR approaches (**Fig. 2b** and **2d**, respectively) for two subjects, confirming the expected increase in signal with the use of additional boluses.



To further investigate the duration of a labeling bolus, the QUIPPS saturation times (TD) were varied from 0 to 800ms in one experiment with TI of 1700 ms. **Fig 3** presents the estimated perfusion MR signals at different TD values. Signal changes were not evident, suggesting that in renal PASL, the duration for a labeling bolus is less than a RR interval. Artificially low renal perfusion values will be obtained if a constant blood velocity is assumed. This pitfall is also applicable to pCASL studies when post-labeling delay longer than a RR interval is adopted.



Conclusion: We have developed and evaluated a new multi-bolus ASL approach to improve SNR in renal perfusion quantification.

References: **1.** Robson, et al, MRM 2009; 61:1374. **2.** Martirosian, et al, MRM 2004; 51:353. **3.** Wu, et al, MRM 2007; 58:1020. **4.** Amanuma, et al, Radiology 1992; 2:559. **5.** Cutajar, et al, Magma 2012; 25:145. **6.** Kim, et al, MRM 1995; 34:293. **7.** Ye, et al, MRM 1997; 37:226. **8.** Wong, et al, MRM 1998; 39:702.