A Look-Locker Acquisition Scheme for Quantitative Myocardial Perfusion Imaging by Arterial Spin Labelling in Humans at 3 T

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Target Audience: ASL, myocardial perfusion

Purpose: Arterial Spin Labelling (ASL) provides a non-invasive alternative to contrast-enhanced Cardiovascular Magnetic Resonance (CMR) imaging, for the investigation of myocardial perfusion. In the standard Flow-Sensitive Alternating Inversion Recovery (FAIR) ASL experiment, two images are collected, one following a slice-selective inversion (SS), the other following a global inversion (GS). In the slice-selective case, the non-inverted inflowing spins entering the image slice cause the value of the myocardial T_1 to be short compared to that acquired for the globally inverted acquisition, where the inflowing spins are fully inverted. This difference in T_1 values is inherently related[1] to the perfusion of the myocardial tissue. Previous studies using ASL to measure perfusion in the human myocardium have employed a single inversion time, which can then be varied between scans[1-3]. However, in small animal imaging, a Look-Locker (LL) style acquisition has been demonstrated[4,5]. In this work we present an efficient Look-Locker based acquisition scheme for FAIR-ASL for use in human subjects, with timing optimised to reduce sensitivity to cardiac motion.

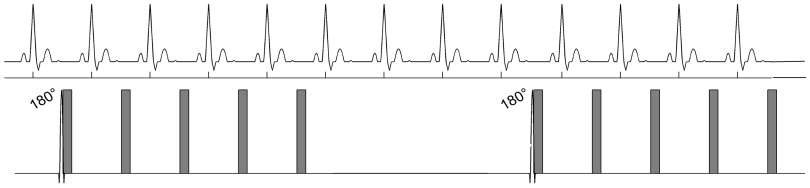

Figure 1: Schematic of the LL-FAIR-ASL pulse sequence over 13 heartbeats. 180° pulses (alternating between SS and GS) are each followed by 5 bSSFP readouts, separated by and R-R interval.

Methods: Data was collected in 4 healthy male volunteers (30 ± 9y) on a clinical Siemens 3 T scanner (Trio, Siemens Healthcare, Germany). Ethics approval was granted for all scans. The LL-FAIR-ASL sequence employed a slice selective inversion, followed by five bSSFP image acquisitions, each synchronised to the R-wave. After a gap of three heart beats, to allow for some recovery of the longitudinal magnetisation, the experiment was repeated with a global inversion within the same 13 R-R interval breath-hold, as shown in Figure 1. This timing guarantees that the signal recovery isn't corrupted by through-plane cardiac motion, by restricting inversions and readouts to the most stable cardiac phase, mid-diastole. The order of the two inversions was then switched, such that the global inversion preceded the slice-selective inversion, and the effect on the mean apparent T_1s investigated. Sequence parameters of the bSSFP readout were flip angle of 35°, an initial value of TI of 130 ms (with the following values being 130 ms + RR, 130 ms + 2RR,…), GRAPPA 2, Partial Fourier 6/8. The imaging slice thickness was 8 mm and the selective and global inversions used an HS8 pulse thickness of 20 mm and ∞ respectively. In each subject the scan was run 5 times for each ordering scheme (SS-GS and GS-SS), such that a total of 10 averages was taken. These ten breath hold scans could be run in less than 15 minutes. The data was fitted for the apparent values of T_1^{SS} and T_1^{GS} using a three-parameter fit. These values from the two ordering schemes were pooled and then used to calculate an estimate of the Myocardial Blood Flow (MBF) using the equation[6]: $MBF = \frac{\lambda}{T_1^{blood}}\left(\frac{T_1^{GS}}{T_1^{SS}} - 1\right)$, where λ = 0.92 mL/g is the blood-tissue partition coefficient.

	SS 1st		GS 1st	
Volunteer	**SS-T_1* (ms)**	**GS-T_1* (ms)**	**SS-T_1* (ms)**	**GS-T_1* (ms)**
1	813 ± 42	882 ± 23	843 ± 19	843 ± 17
2	887 ± 22	947 ± 51	892 ± 16	960 ± 24
3	743 ± 35	958 ± 88	848 ± 47	840 ± 25
4	939 ± 14	982 ± 10	957 ± 17	980 ± 11

Table 1: Mean apparent T_1 values for each volunteer, with standard deviations for both SS-GS and GS-SS ordering schemes

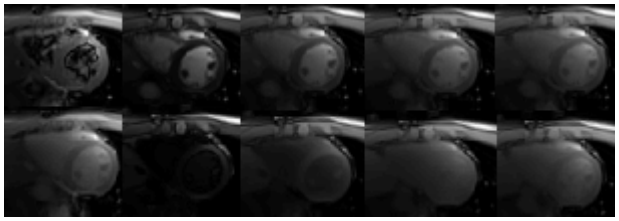

Figure 2: Image series showing the recovery of the longitudinal magnetisation over 5 RR intervals for both the slice-selective (top) and globally selective (bottom) inversions.

Volunteer	MBF (mL/g/min)
1	1.58 ± 0.76
2	2.16 ± 1.38
3	3.94 ± 0.55
4	1.09 ± 0.17

Table 2: Mean MBF values in with standard deviations

Results & Discussion: Figure 2 shows an image series typical of those collected, showing the differing effects of the SS and GS inversion recovery. Table 1 shows the mean apparent T_1 values for each of the four volunteers. It can be seen that, although in both ordering schemes the magnetisation recovers quicker in the slice-selective case, the difference between the apparent T_1s (SS and GS) when the global inversion is applied first is significantly reduced. This occurs due to incomplete recovery of the magnetisation between inversions, which in the GS-SS case also affects inflowing spins. As the calculation of myocardial perfusion relies on the ratio between these two values of the apparent T_1, it is important to employ both ordering schemes in order to eliminate any bias which may occur due to the incomplete recovery. Although the calculated values for apparent T_1 are not stable between volunteers, the results for each proved to be reproducible, with low values for the standard deviation. Values for MBF for the four volunteers, in mL/g/min, are presented in Table 2. Previously reported values for MBF using single TI myocardial ASL techniques have been presented, in the range 0.74-2.40 ± 1.2 mL/g/min, in normal volunteers at rest.

Conclusion: The use of a Look-Locker acquisition for a FAIR-ASL experiment allows for the collection of an entire time series for both SS and GS inversion in a minimum of two breath holds, with reordering of inversion pulses, while restricting both the inversion pulses and readouts to the most stable cardiac phase, mid-diastole. It allows for the calculation of reproducible values of the apparent T_1, which can be used to calculate and estimate of the MBF. This can be achieved in 13 heartbeats, without the use of intravenous contrast agents, which makes this an attractive and viable technique for the investigation of myocardial perfusion and changes in perfusion in patients.

References: (1) Zun et al, MRM 2009; 62:975-983. (2) Wacker et al, JMRI 2003; 18:555-560. (3) Wang et al, MRM 2010; 64:1289-1295. (4) Campbell-Washburn et al, MRM 2013; 69: 238-247. (5) Kober et al, MRM 2004; 51:62-67. (6) Belle et al, JMRI 1998; 8:1240-1245.

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