Measuring myocardial blood flow using modified look locker inversion (MOLLI) recovery arterial spin labelling (ASL)

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TARGET AUDIENCE: MR researchers and clinicians interested in the measurement of myocardial blood flow and ASL.

PURPOSE: Myocardial blood flow (MBF) is an important marker of cardiac function. The gold standard for measuring MBF is PET, but this involves ionising radiation. Arterial spin labelling (ASL) has previously been used to non-invasively measure MBF in humans without the need for contrast agent [1-5], but this is non-trivial due to low myocardial blood flow and motion of the heart. Here we use a cardiac-triggered modified look-locker inversion [6] ASL (MOLLI-ASL) scheme to measure MBF in healthy control subjects (HC) and in patients with chronic kidney disease (CKD). In addition, an exercise stress test is used to assess the sensitivity of the technique [1,3].

METHODS: 10 subjects were scanned; five stage 3 CKD patients (2M/3F, mean age 52 ± 6y) and five healthy controls (age and gender matched). Scanning was performed on a 3T Phillips Achieva scanner (MultiTransmit, 16-channel SENSE torso receive coil). Localiser cine images were initially collected to define the short axis of the left ventricle (LV). A cardiac-triggered MOLLI recovery ASL scheme (Figure 1) was performed using a FAIR labelling scheme (selective (S) width 35 mm, non-selective (NS) width 350 mm) with in-plane pre- and post-saturation pulses using a bFFE readout (FOV 288x288x5 mm, FA 35^{o}, centric half-Fourier acquisition, SENSE 2, TE/TR = 1.57/3.14 ms). A 'Trigger-delay' (TD) was used prior to the label module to allow data to be collected at a range of post-label delay times. 8 TD values of 0 – 350 ms in 50 ms steps were collected, with 3 readout pulses per Look-Locker ASL (LL-ASL) set, resulting in a MOLLI recovery curve with 24 time points. An 'End-delay' period of 3000 ms followed the LL readout pulses to ensure full recovery of longitudinal magnetisation between S/NS pairs. Physiological logs were recorded.

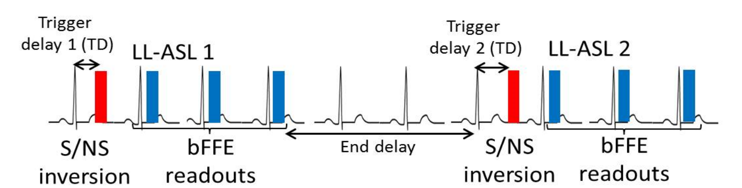

Figure 1: MOLLI ASL scheme: Example of two LL-ASL sets with different TD. 8 sets were collected to yield a S/NS set of 24 points.

Equation 1:

$$\boldsymbol{MBF} = \frac{\lambda}{T_{1,blood}}\left(\frac{T_{1,NS}}{T_{1,S}} - 1\right)$$

Exercise stress challenge: A Grip Force Bimanual Fibre Optic Response Pad (Current Designs, Philadelphia) was used. Subjects were asked to push against the hand grip resistance until they reached a target maximum force level, and to hold this force level for ~ 5 minutes during MR acquisition, with feed-back provided to the subjects on their force level throughout. MOLLI ASL data were collected at rest and on exercise.

Data Analysis: All data were inspected for motion and discarded if required. ROIs were drawn in the myocardium and LV blood pool. Physiological logs were used to calculate the exact time for each readout pulse. Using these timings, the S and NS recovery curves were iteratively fitted for T_{1S} and T_{1NS}, and MBF calculated using Equation 1 [7] (where $\lambda = 0.92$) assuming inflowing blood is fully recovered for the S inversion. T_{1blood} was fitted to an inversion recovery from the NS LL recovery data in the LV ROI.

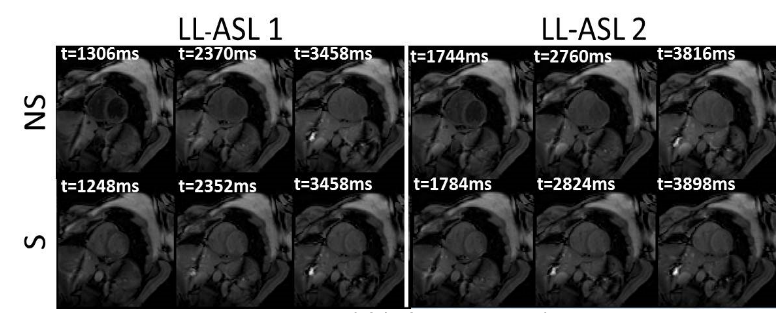

Figure 2: Example images of S/NS data at 2 of the 8 trigger-delay periods (TD = 100ms and 250ms respectively)

RESULTS: Example S/NS images from example LL readouts at two different TDs are shown in Figure 2. There was no significant difference between groups for calculated T_{1blood} values (T_{1blood} = 1.8 ± 0.1 s – mean across groups). At rest, MBF (mean ± SEM) was 1.25 ± 0.45 ml/g/min in the HC group and 1.34 ± 0.42 ml/g/min in CKD patients. Figure 3 shows MBF (mean ± SEM across the group) at rest and on exercise for both HC and CKD groups. A significant increase in MBF was found between rest and exercise for CKD patients (mean increase in MBF = 85 ± 24 %, p = 0.01), with a trend for an increase on exercise for HC (mean increase in MBF = 43 ± 10 %).

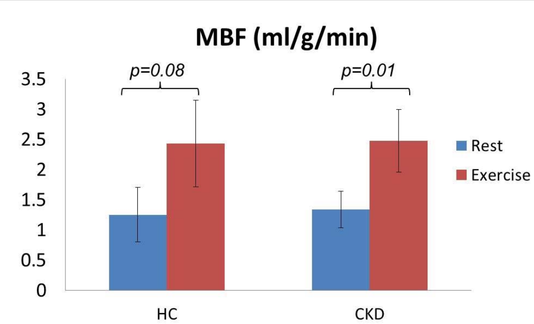

Figure 3: MBF at rest and during the exercise stress challenge in HC and CKD.

DISCUSSION: This study demonstrates the use of a cardiac-triggered MOLLI ASL technique to quantify MBF in a scan time of 5 minutes. Values of MBF measured here in HC are in agreement with those in the literature [1-5]. For both the CKD and HC groups, an increase in MBF was found on exercise (Fig. 3). This technique will now be used to be used to further explore changes in myocardial function in CKD and correlate with clinical assessment measures.

References: [1] Wang *et al.* MRM. 2010; 64(5):1289-1295, [2] Zun *et al.* JACC. 2011; 4(12):1253-61 [3] Zun *et al.* MRM. 2009; 62:975-83, [4] Do *et al.* JCMR 2014; 16:15, [5] Northrup et al. JCMR 2008; 10:53, [6] Messroghli *et al.* MRM. 2004; 52:141-146, [7] Belle *et al.* JMRI 1998; 8:1240-1245.