Improved Reliability of Cardiac Perfusion MRI using Free-breathing Myocardial ASL with Navigator-echo (FREEMAN)

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Introduction

Myocardial blood flow (MBF) or perfusion is an important index of ischemic heart disease. To date, human myocardial perfusion analysis is generally performed using SPECT/PET and/or first-pass perfusion MRI which involves radiation and gadolinium-based contrast agent respectively. Arterial spin labeling (ASL) has recently been applied for assessing myocardial perfusion in both animal and human studies (1-3). ASL MBF measurement has been validated against the microsphere technique and first-pass perfusion imaging in rats. Notably, ASL has been shown to be promising in its applications to patients with coronary artery disease (CAD) (4, 5). The existing ASL myocardial perfusion methods, nevertheless, have limitations when adapted to clinical settings. The requirement for repeated breath holds may be challenging for CAD patients. Image misregistration between multiple breath holds due to heart rate variation and/or patient motion are another potential source of error. In this study, we developed a cardiac perfusion MRI technique – dubbed FREE-breathing Myocardial ASL with Navigator-echo (FREEMAN) – for reliable MBF measurements under clinical settings.

Methods

Seven healthy subjects (age 27-58yrs, 6 males) participated in this study on a Siemens 1.5T Espree system after they provided written informed consent. The pulse sequence diagram is shown in Fig. 1. Imaging parameters were: FOV=30cm, matrix=116x128, 3 segments, TR/TE=4/2 ms. A single slice (8mm) along the short axis of the left ventricle (LV) was measured 32 times (16 pair label/control) for each of the 4 or 5 TIs between 200 and 1700ms. The scan time for a single TI was approximately 5min. Scans were navigator-gated and ECG-triggered for controlling respiratory and cardiac motion. The selective inversion and saturation pulses were 3-4cm thick to avoid potential displacement of the imaging slice between label and readout. Residual motion was further corrected using a Siemens online nonrigid motion correction (MoCo) program (6). Control and tagging images were pair-wise subtracted and averaged using custom IDL software. The mean difference signals (dM) were measured from 3 ROIs: myocardium, blood pool (ventricle) and background muscle. The dynamic myocardial dM signals with multiple TIs were simultaneously fitted for MBF and arterial transit time (ATT) in each subject based on a standard kinetic model. The scan with 900ms TI was repeated in 5 subjects to test the reliability which was measured by intraclass correlation coefficient (ICC). Scans with multiple (n>3) 20s breath hold were carried out in 5 subjects for comparison.

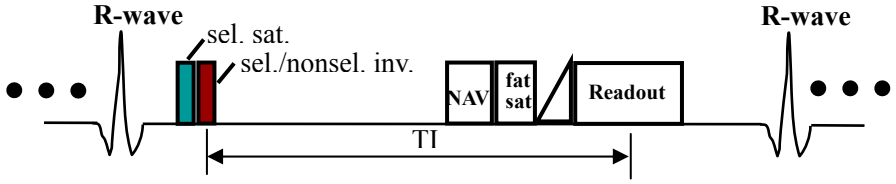

Fig. 1 FREEMAN combines ASL (FAIR in this study) with a navigator-gated, ECG-triggered TrueFISP readout sequence. Selective and nonselective inversion pulses are used for label and control acquisitions respectively. A saturation pulse is applied prior to labeling pulses to minimize the variations in heart beat. Navigator-echo is placed on the diaphragm that allows image readout during the end-expiration phase. Image acquisition is always during the mid-diastole cardiac phase.

Results and Discussion

Figure 1 displays the difference perfusion images (dM) acquired at 4 delays in a representative subject. Myocardium signals appear uniform after prospective gating and inline motion correction. The average dM of myocardium perfusion, ventricle blood and background muscle are displayed in Fig. 2. The dM signals are expressed as the fraction of the equilibrium myocardium signal (M0) fitted from the multi-delay data. As can be seen, the mean myocardial signal has a transit delay of approximately 400ms and peaks around 900-1300ms, whereas the blood pool signal peaks earlier (500-900ms). Without inline MoCo, the measured myocardium signal shows "suprious" elevation at long delays (1300-1700ms). Quantitative model fitting was performed in each subject. With inline MoCo, the average fitted MBF is 102.7 ml/100g/min (SD 56.3, range 37-187), mean ATT is 377.1ms (SD 106.3, range 229-500). Without MoCo, the average fitted MBF is 141.3ml/100g/min (SD 72.9, range 61-271), mean ATT is 443.1ms (SD 214.8, range 210-818). Test-retest results are displayed in Fig. 4. The data show low reliability (ICC=0.41) without MoCo and moderate reliability (ICC=0.61) with inline MoCo respectively. One repeated scan was identified as outlier (Fig. 4) since the dM/M0 signal in background muscle was 2% (<0.2% in the rest scans), indicating severe motion. Excluding this scan, moderate (ICC=0.59) and high (ICC=0.95) reliability was achieved without and with inline MoCo respectively. The data consistently show that inline MoCo improves reliability of MBF measurements. With breath holding, the estimated MBF is 3 times higher (mean±SD=347±146ml/100g/min). In summary, the estimated MBF in healthy subjects using FREEMAN matches existing MRI and PET literature (1, 7) with a mean ATT around 400ms and moderate to high test-retest reliability (ICC=0.6-0.95). Further developments include implementing FREEMAN at high magnetic fields and larger scale clinical validations.

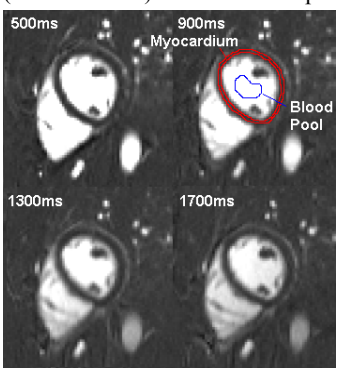

Fig.2 Difference perfusion images of a representative subject with 4 delays.

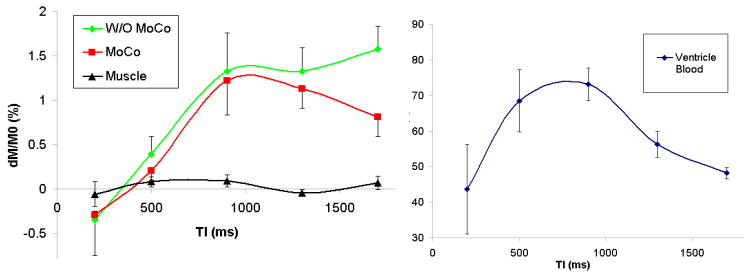

Fig.3 Mean dM/M0 signals of myocardium perfusion, ventricle blood and background muscle. Error bars indicate S.E.M.

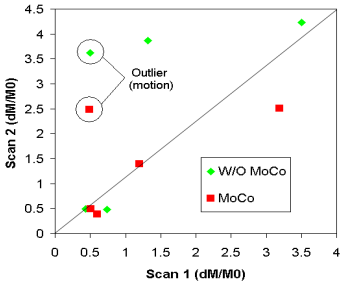

Fig.4 Test-retest results from 5 subjects, one outlier was identified due to severe motion.

References [1] Zhang et al MRM 53;1135 (2005) [2] MoCommis et al MRI 26:11 (2008) [3] Northrup J et al Cardiovas MR 10:53 (2008) [4] Waller et al Circulation 103:1564 (2001) [5] Wacker et al JMRI 18:555 (2003) [6] Chefdhotel et al Proc. ISBI (2002) [7] Chareonthaitawee et al Cardiovasc Res 50: 151 (2001)