Arterial Spin Labeled Myocardium Perfusion Imaging with Background Suppression

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Introduction

Arterial spin labeling (ASL) is widely used for assessing cerebral blood flow (CBF). However, its application to myocardial blood flow (MBF) has been limited [1-2]. Current methods may suffer from artifacts due to high LV blood signal, and from lack of measurement consistency. In this work, we investigate ASL cardiac perfusion imaging using flow-sensitive alternating inversion recovery (FAIR) [3] with background suppression (BGS) [4-5]. We demonstrate that the ASL signal follows a non-central chi distribution, and determine the number of averages needed for reliable MBF quantification. Studies performed in healthy volunteers yield perfusion rates comparable to published literature values.

Methods

Pulse Sequence: The FAIR-BGS pulse sequence is illustrated in Figure 1. BGS is expected to reduce the effects of mis-registration and ringing from high LV blood signal [6]. It is achieved using a saturation – inversion – inversion preparation scheme that is designed to suppress a broad range of T_1s including myocardium (1000-1200ms) and blood (1400-1600ms) at 3 T [7]. Adiabatic saturation and inversion pulses (BIR4 and hyperbolic secant) were used to reduce sensitivity to B0 and B1 inhomogeneity. The first inversion pulse alternated between being non-selective or slab-selective to generate control and tagged images respectively. A snapshot SSFP acquisition is used for its high SNR efficiency. Imaging parameters were flip angle = 40°, TR = 3.2ms, FOV = 20cm, matrix size = 96x96, and slice thickness = 10mm. The first inversion and the center of the imaging acquisitions occur at the same cardiac phase (mid-diastole) to ensure that the inversion slab contains the imaging slice, and the calculated perfusion rate reflects average perfusion over one heartbeat. Experiments were performed in four healthy volunteers on a GE Signa 3.0T EXCITE scanner with an 8-channel cardiac coil.

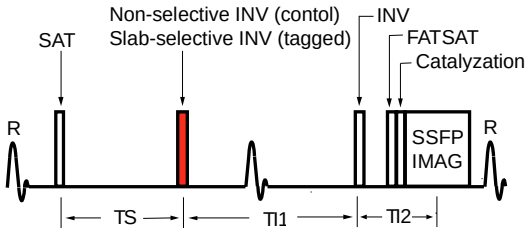

Figure 1. Proposed cardiac ASL pulse sequence timing: flow-sensitive alternating inversion recovery (FAIR) with background suppression (BGS).

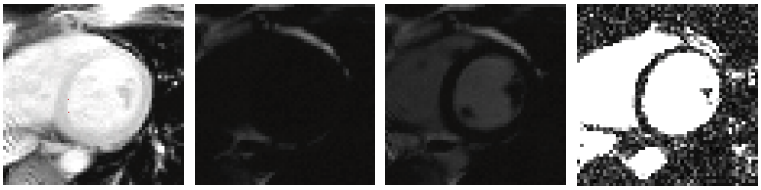

Figure 2. Short-axis FAIR images from a healthy volunteer. (a-c) are windowed identically. (d) illustrates that myocardial ASL signal is comparable to background noise before averaging over multiple breath-holds.

Statistics: Perfusion rate is calculated using: $f = (T - C) / (2 \cdot B \cdot RR \cdot (1-exp(-TS/T_1)) \cdot exp(-(TI1+TI2)/T_1))$ where B, T, and C represent the baseline image (no preparation), the tagged image, and the control image, respectively. The ASL signal is the relatively small difference between tagged and control image pixels, which can be considered a random variable. Let X denote $(T - C)$. With 8-channel reception and sum-of-squares reconstruction, $X = \sqrt{\sum_{k=1}^{8}\left((T_{Rk}-C_{Rk})^2+(T_{Ik}-C_{Ik})^2\right)}$ where $T_{Rk}+iT_{Ik}$ and $C_{Rk}+iC_{Ik}$ represent complex pixel intensities of tagged and control images from k^{th} channel. When $(T_{Rk} - C_{Rk})$ and $(T_{Ik} - C_{Ik})$ follow Gaussian distribution of $N(m_{Rk}, \sigma^2)$ and $N(m_{Ik}, \sigma^2)$ respectively, X/σ follows a non-central chi distribution with a parameter $\lambda = \sqrt{\sum_{k=1}^{8}\left((m_{Rk}/\sigma)^2+(m_{Ik}/\sigma)^2\right)}$ where $\sigma = \sqrt{2/N_{avg}} \cdot \sigma_N$ where N_{avg} is the number of averages and σ_N is the standard deviation of Gaussian noise [8]. Let $m = \sqrt{\sum_{k=1}^{8}\left(m_{Rk}^2+m_{Ik}^2\right)}$ and $B = \sqrt{\sum_{k=1}^{8}\left(B_{Rk}^2+B_{Ik}^2\right)}$ where $B_{Rk}+iB_{Ik}$ represents complex pixel intensity of baseline image from k^{th} channel. For healthy myocardium, we can estimate m/B from literature values given timing of proposed sequence assuming that B is deterministic. Since $m/B = \lambda \cdot \sigma/B = \lambda \cdot \sqrt{2/N_{avg}} \cdot \sigma_N/B$, λ is determined and the probability density function (pdf) of X can be found. Based on this pdf, the N_{avg} that guarantees $Prob(|X - m| < 0.1m) > 90\%$ (i.e. MBF measurement will be within 10% of the true value 90% of the time) is 8000 to 13000 for heart rates of 60 to 70 bpm. For CBF perfusion imaging, the N_{avg} that satisfies the same confidence criteria is roughly 50, because the SNR of state-of-the-art head coils is ~5 times higher than that of cardiac ones, and ASL signal is approximately tripled without BGS.

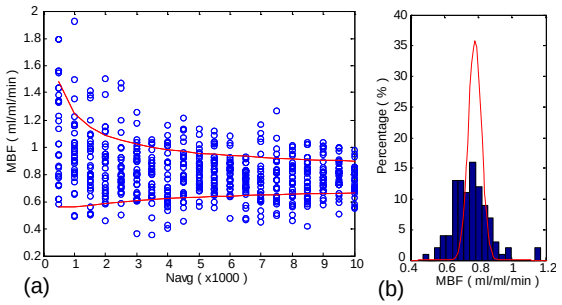

Figure 3. (a) Measured MBF distribution (blue circles) and mean±3SD of expected non-central chi distribution (red lines) as a function of N_{avg} (b) Histogram of measured MBF (blue bars) and pdf of expected non-central chi distribution (red line) for N_{avg}=10000.

Results

Figure 2 contains FAIR-BGS images from one representative volunteer. We acquired 4 control and 4 tagged images per breath-hold, and performed 20-50 breath-holds per volunteer. To achieve N_{avg} > 10000, pixels were averaged over all myocardium as well as over multiple breath-holds. Figure 3 illustrates the agreement between the measured distribution and predicted non-central chi distribution. The measured distribution is broader, which may be due to spatial variation of true perfusion rates or contamination of myocardial signal by the LV blood pool. The average MBF measurement of 0.76 ml/ml/min for N_{avg}=10000 is comparable to the literature value of 0.80 ml/ml/min for MBF in healthy myocardium.

Discussion

This study demonstrates initial feasibility of assessing MBF using ASL at 3 T. Confident quantification of MBF continues to be limited by SNR, even at 3 T. Possible improvements could come from more efficient tagging schemes, more SNR-efficient acquisition, or the incorporation of respiratory navigation (rather than multiple breath-holds). BGS reduces the ASL signal by roughly 50%, but also reduces potential for artifacts from the LV blood pool. It may eventually allow for non-subtractive ASL, which would increase SNR efficiency.

References

[1] An J *et al*, 13th ISMRM p253, 2005. [2] Zhang H *et al*, MRM 53:1135, 2005. [3] Kim SG, MRM 34:293, 1995. [4] Ye FQ *et al*, MRM 44:92-100, 2000. [5] Duyn JH *et al*, MRM 46:88-94, 2001. [6] Zun Z *et al*, 11th SCMR 2008. (submitted) [7] Noeske R *et al*, MRM 44:978, 2000. [8] Constantinides CD *et al*, MRM 38:852, 1997.