Breath-hold Arterial Spin Labeling TrueFISP MRI of Myocardial Perfusion

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Introduction: Assessment of regional myocardial perfusion is of critical importance for the functional evaluation of coronary heart disease. In the present work, we describe a breath-hold arterial spin labeling (ASL) trueFISP imaging method for the quantitative mapping of absolute myocardial perfusion.

Methods: In the current implementation, a segmented trueFISP sequence was combined with a FAIR [1-2] spin labeling technique, in which slice-selective and slice-nonselective inversion pulses were applied alternately to generate two sets of images (control and label) in a 16-20 sec breath-hold scan (Figure 1). Inversion pulses were applied every other heart beat. Inversion time TI (time between the center of inversion pulse and the center of the data acquisition window) was set the same as one R-R interval to make sure that images are acquired at the same cardiac phase as that of the inversion pulses. Segmented TrueFISP sequence, because of its high SNR, was used for image acquisition. Six healthy volunteers were studied on a 1.5T clinical scanner (Magnetom Sonata, Siemens, AG). Phased array coils were used in all experiments. Imaging parameters were: TR/TE = 3.0ms/1.5ms, section thickness = 10-12 mm, matrix size = 128-192 x 128-192, and field of view = 30 -35 cm.

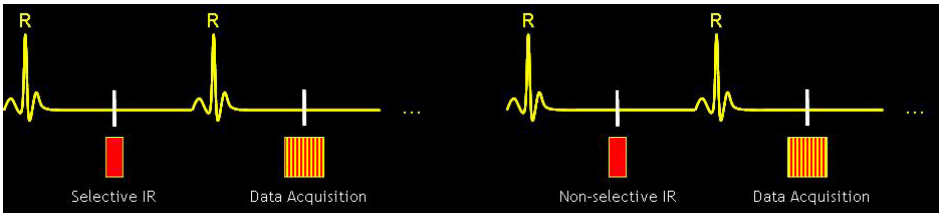

Figure 1. Two sets of images, one with the application of slice selective inversion (control) and one with slice non-selective inversion (label) were obtained in a single breath-hold. Segmented true FISP was used for data acquisition.

Theory

When inversion RF pulses are applied repeatedly at an interval τ less than the time required for full recovery, the equation that describes the longitudinal relaxation of the magnetization M towards its equilibrium M_0 can be derived from the Block's equations as:

$$M(\mathrm{TI}) = M_0 \frac{\left[1-\exp(-\mathrm{TI}/\mathrm{T}_1)\right] - \alpha\left[\exp(-\mathrm{TI}/\mathrm{T}_1) - \exp(-\tau/T_1)\right]}{1+\alpha\exp(-\tau/T_1)} \qquad (1)$$

Where TI is the inversion time, and α = -cos(θ) represents the effect of an imperfect inversion (for a complete inversion, α equals to unity). In slice non-selective inversion, the magnetization of blood water returns to its equilibrium according to Equation 1, whereas in slice selective inversion the magnetization of blood water entering the slice of interest stays at its equilibrium state. It can then be shown that, for an imaging experiment illustrated in Fig. 1, assuming T1 of the blood is the same as that of myocardium, the relationship between myocardial perfusion f and the signal difference ΔS is [3]:

$$\Delta S = S_0 \cdot TI \cdot \left(\frac{f}{\lambda}\right) \cdot \left(\frac{(1+\alpha)\exp(-\mathrm{TI}/\mathrm{T}_1)}{1+\alpha\exp(-\tau/T_1)}\right) \qquad (2) \qquad \text{or} \qquad f = \left(\frac{\Delta S}{S_0}\right) \cdot \left(\frac{\lambda}{TI}\right) \cdot \left(\frac{1+\alpha\exp(-\tau/T_1)}{(1+\alpha)\exp(-\mathrm{TI}/\mathrm{T}_1)}\right) \qquad (3)$$

Where λ is the blood/tissue water partition coefficient, ΔS is the signal difference between control and labeled images, and S_0 the signal intensity under fully relaxed conditions. Equation 3 indicates that f is linearly related to ΔS and, when all other MRI parameters (S_0, TI, T1,α, τ) are known, absolute myocardial perfusion can be determined from the image data.

Results: Three short-axis signal difference images obtained at three different levels are shown in Fig. 2. In order to quantify these data, slice non-selective inversion recovery MR images were also collected at 10 different inversion time and then fit to Equation 1 to extract MRI parameters T1 and M_0 (Fig. 3). In one study, using τ = (2 R-R interval) ~ 2 sec, TI ~ 1000 ms and assuming a complete inversion (α = 1.0), myocardium perfusion was estimated as f = 2.54 ml/g/min using Equation 3.

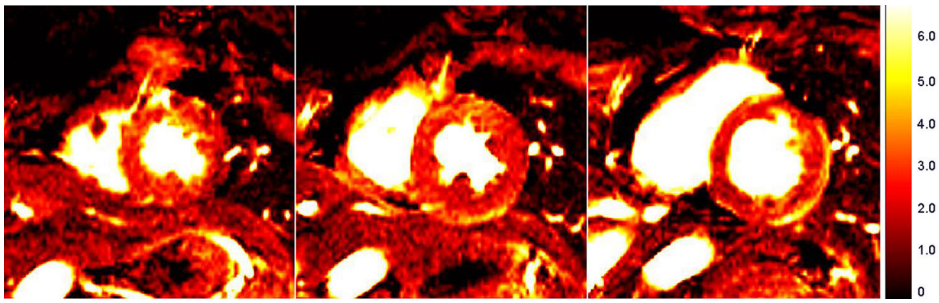

Figure 2. Myocardial perfusion map shown as signal difference between control and labeled images. Note that signal difference in fat tissue is near zero as compared to the high signal difference in myocardium.

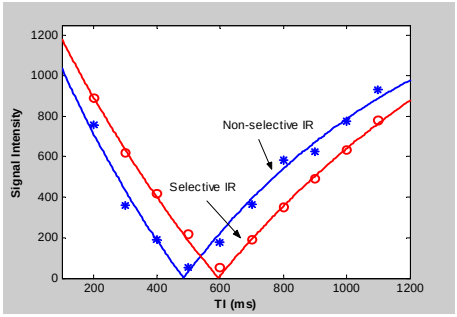

Figure 3. SI vs. TI with slice selective and non-selective inversion fit to theory.

Discussion: Arterial spin labeling (ASL) perfusion MRI, i.e. the use of magnetically labeled flowing blood as an endogenous contrast agent for the measurement of regional blood flow, offers the advantages of high spatial resolution and does not require contrast injections [1-2,4-5]. While this technique is widely used for quantitative measurements of cerebral blood flow, its application in measuring human myocardial perfusion has been rather limited [6-7]. Our current work shows that the combination of a segmented high-SNR trueFISP imaging with the FAIR technique may provide a practical method for the imaging and quantification of myocardial blood flow. This ability of MRI to quantitatively measure regional myocardial perfusion may have significant impact in the evaluation of ischemic heart disease.

References

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