# Study of Magnetization Behavior of MR Tagging with Steady State Free Precession

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**Introduction:** MR tagging is a widely used technique for non-invasive cardiac motion analysis. Tags can be applied either in the phase-encoding or readout direction to assess in-plane wall motion, or in the slice-selection direction to measure the through-plane strain of cardiac muscle, as in strain encoded (SENC) MRI [1]. MR tagging was originally implemented in a gradient echo sequence, but recently has also been investigated with balanced steady-state free precession (SSFP) [2-5]. Compared with spoiled gradient echo (SPGR), SSFP permits a shorter TR, which translates into higher temporal resolution or shorter image acquisition time, and produces higher SNR, which in turn generates higher tag contrast. However, the signal behavior of MR tagging with SSFP has not yet been thoroughly investigated. In this study, the steady state behavior of MR tagging with SSFP has been further explored,

**Methods:** Myocardial tagging using SSFP is implemented by periodically applying tagging preparation pulses among a series of $\pm\alpha$ pulse train. After the detection of the R wave of ECG signal, the $\pm\alpha$ pulse train is interrupted. An $\alpha/2$ flip-back pulse is applied to restore the magnetization in the longitudinal direction. A 1-1 SPAMM (spatial modulation of magnetization) tagging pulse is then applied and followed by an $\alpha/2$ preparation excitation pulse. Unlike the normal usage of SSFP, the tagged image is acquired during the transient state of SSFP instead of the steady state. This is because the tags only exist at the transient state and will disappear when the signal reaches the steady state.

We denote the period of the cardiac cycle as Tc and the number of cardiac cycles (after the start of the acquisition) as *n*. Theoretically the magnetization in the longitudinal direction at the end of $n^{\text{th}}$ cardiac cycle can be written as:

$M_z^{(n)}(\mathbf{x}) = M_0 \cdot \cos^n(\varphi(\mathbf{x}))e^{-nT_C/T_1^*} + M_{SS}\cdot(1-e^{-T_C/T_1^*})\cdot(1-\cos^n(\varphi(\mathbf{x}))e^{-nT_C/T_1^*})/(\sin\frac{\alpha}{2}\cdot(1-\cos(\varphi(\mathbf{x}))e^{-T_C/T_1^*}))$, where $\varphi(\mathbf{x})$ is the spatially modulated tag phase, $M_{ss}$ is the steady state magnetization, and T1* is the relaxation time as defined in [6]. Note that T1* is a function of T1, T2 and flip angle $\alpha$, and is much shorter than T1. After a few cardiac cycles, $e^{-nT_C/T_1^*}$ is close to zero. The above equation can then be simplified as: $M_z^{(n)}(\mathrm{x}) = M_{SS}\cdot(1-e^{-T_C/T_1^*})/(\sin\frac{\alpha}{2}\cdot(1-\cos(\varphi(\mathrm{x}))e^{-T_C/T_1^*}))$. This means $M_z^{(n)}(\mathrm{x})$ remains the same at later cardiac cycles, and the magnetization enters a stable state, which we call *steady transient state*. In the steady transient state, the transversal magnetization decays exponentially with a time constant T1* $M_{xy}(\mathrm{x},t) = M_{SS}(1-e^{-T_C/T_1^*})/(1-\cos(\varphi(\mathrm{x}))e^{-T_C/T_1^*})\cdot\cos(\varphi(\mathrm{x}))e^{-t/T_1^*} + M_{SS}(1-e^{-t/T_1^*})$. Note that the tagging profile is no longer a perfect sinusoidal function. The tag contrast can then be written as $C_{Tag}(t) = 2M_{SS}e^{-t/T_1^*}/(1+e^{-T_C/T_1^*})$. This means the tag contrast decays with T1* and is higher with longer Tc.

**Results:** The numerical simulation (myocardium) was performed using the following parameters: T1=870ms, T2=55ms, TR=5ms, Tc =750ms and $\alpha$=28°. $T_1^*$ is calculated as 466 ms based on [2]. Fig. 1 shows how the transversal spatially modulated magnetization changes with time at different $\varphi(\mathbf{x})$. If the SSFP pulse train is not interrupted, the magnetizations starting from different tag angles all reach the final steady state $M_{ss}$ in about 3 seconds (Fig. 1a). After that the tags completely disappear. However, if the SSFP pulse is interrupted by the tagging pulse at the end of each cardiac cycle, the cardiac cycle is not long enough to make the magnetization reach the steady state. In this case, the magnetization enters the steady transient state after 2 to 3 cycles (Fig. 1b).

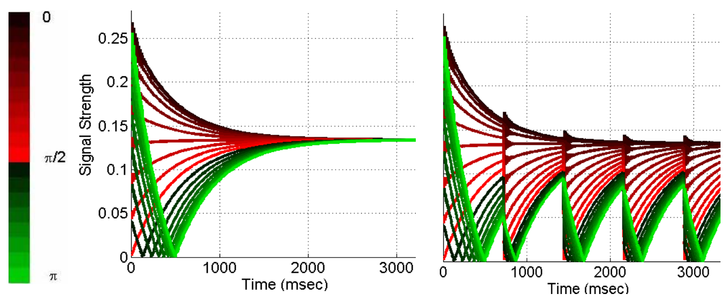


Fig. 1 (a) (b)

A liquid phantom with estimated T1=350 ms, T2=90 ms was used in the phantom study. The imaging parameters were: TE=3.71 ms, bandwidth=300 Hz/pix, segments=3, acquisition matrix 256x256, FOV=300 mm, slice thickness=12 mm, Tc=1 second, flip angle=30°, tag separation=50 mm. The image series was acquired in 86 cycles. Fig. 2a shows one of the tagged phantom images. Fig. 2b shows the signal changes of both simulation and phantom results at different tag phase $\varphi(\mathbf{x})$ as functions of time (solid line for simulation and dotted line for phantom experiment). The phantom results fit well with the computational simulation.

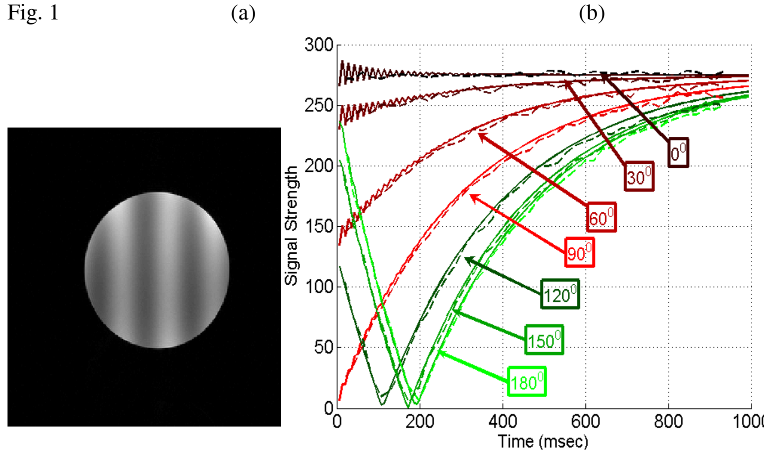


Fig. 2 (a) (b)

**Conclusion:** In this work, the magnetization behavior of MR tagging with SSFP was evaluated. Based on the results, a reduction in artifacts is likely if a few cardiac cycles can be skipped after the scan starts and the images are acquired after the signal reaches the steady transient state. The theoretical analysis of the signal behavior provides a better understanding of cardiac tagging with SSFP which has the potential to benefit imaging protocol planning and sequence design.

**References:**

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