SAR-efficient 3D Cardiac CINE with Respiratory-Triggered RF Gating

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Introduction: Cardiac CINE is the gold-standard method for assessment of the functional parameters of the heart such as ejection fraction or ventricular mass. Clinically, multiple breathhold 2D CINE steady-state free precession (SSFP) scans are performed to cover the entire ventricle. However, variations in breathhold positions can result in slice-to-slice misregistration and thus errors in volume assessment. While the feasibility of 3D CINE SSFP has been demonstrated [1], its clinical use remains limited due to the low contrast-to-noise ratio (CNR) between blood and myocardium [2], respiratory motion [3] and the high specific absorption rate (SAR). Thus, a 3D CINE approach that addresses these challenges and minimizes patient discomfort (free-breathing, low SAR) while providing accurate functional assessment of the heart (high CNR, no misregistration, no motion artifacts) would be desirable. Here we propose a new method that addresses these problems by gating the radiofrequency (RF) pulses using an external respiratory sensor (bellows) to coincide with image acquisition. The proposed approach (3D $CINE_{RFG}$) is compared to non-RF-gated 3D CINE (3D $CINE_{REF}$) and multiple breathhold 2D CINE.

Methods: For both 3D acquisitions, the respiratory bellows was used to gate the acquisition for respiratory motion by only acquiring data in the expiratory phase. While for 3D $CINE_{REF}$, RF excitation was performed continuously irrespective of respiratory phase, for 3D $CINE_{RFG}$, the RF excitation was turned on or off based on the respiratory cycle. Based on the continuous monitoring of the respiratory motion using the bellows signal, the excitation RF pulses were set to be active during end expiration and set to be off during inspiration. Figure 1 (a) and (b) shows 3D $CINE_{RFG}$ acquisition scheme (for simplicity only 4 cardiac phases are illustrated). Switching off the RF pulses during inspiration reduces the overall SAR and allows for T_1-recovery of the tissues. The M_z difference between blood an myocardium is larger during the transient phase compared to the steady-state, as illustrated in Figure 1 (c), which could lead to increased CNR. The penalty for switching off the RF is that the steady-state is lost. To address this drawback and to minimize signal oscillations during the early transient phase, an RF ramp-up scheme is performed during the first acquired cardiac phase within the gating window. This cardiac phase is often not used for reconstruction as only an RR-interval completely acquired within the gating window is accepted. Four healthy subjects were used for the experiments. 3D-$CINE_{RFG}$ images were acquired in the short-axis view covering the left ventricle (LV) with the following parameters: FOV=300x300x100mm, 2x2x8mm acquired resolution (reconstructed to 1.2x1.2x4mm^3), 20 frames/cardiac cycle, α=45˚, TE/TR=1.6/3.2. For comparison, 3D $CINE_{REF}$ using conventional continuous acquisition as well as multiple breath-hold 2D CINE with similar imaging parameters was acquired. LV ejection fraction (LVEF) and LV end-diastolic mass (LVEDM) were measured for all acquired datasets. Relative SNR (rSNR) and CNR (rCNR) were calculated for the 3D CINE methods. Average SAR, calculated as $SAR_{AV}=RF_{ON}/RF_{TOT}$, was computed for 3D $CINE_{RFG}$ (SAR_{AV}=1 for 3D $CINE_{REF}$). Two-tailed paired *t*-test was used to compare the measurements ($p < 0.05$ = statistically significant differences).

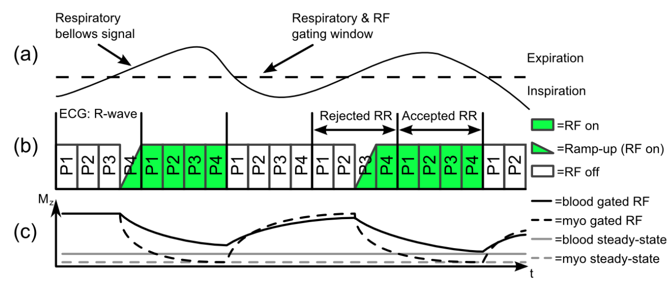

Figure 1. Respiratory bellows signal (a) used to gate a 3D CINE sequence (b) for motion and RF excitation. The resulting M_z magnetization of blood and myocardium (myo) is shown in (c) along with the steady-state values.

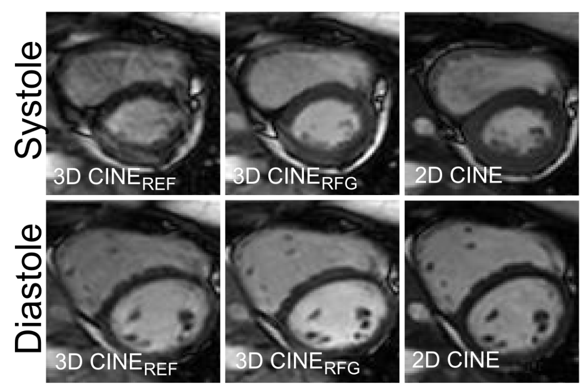

Figure 2. Respiratory gated 3D CINE images using no RF gating (3D $CINE_{REF}$), with RF gating (3D $CINE_{RFG}$) and breath-hold 2D CINE (2D-C) in systole and diastole.

Table 1. LV measurements. Values as mean (standard deviation).

	LVEF (%)	LVEDM (g)	rSNR	rCNR
3D $CINE_{REF}$	60.8 (2.0)	69.9 (11.4)	26.4 (5.4)	20.1 (4.8)
3D $CINE_{RFG}$	60.4 (2.4)	72.5 (11.4)	32.1 (9.4)	23.5 (7.2)
2D CINE	60.0 (1.7)	75.2 (15.6)	-	-

Results: Figure 2 shows CINE images in end diastole and end systole, acquired with 3D $CINE_{REF}$ (left), 3D $CINE_{RFG}$ (middle) and 2D CINE (right). LV measurements are summarized in Table 1. No statistical differences were found between the three CINE methods for LVEF or LVEDM. Average SAR for the 3D $CINE_{RFG}$ sequence was 56% i.e. the approach nearly halves the SAR compared to 3D $CINE_{REF}$.

Conclusion and Discussion: In this work we demonstrated the feasibility of using respiratory bellows for both respiratory motion gating and SAR reduction. The proposed RF gating substantially lowers the SAR (44%) without any SNR or CNR penalty. Further study in larger cohorts of patients is now warranted to assess the efficacy of respiratory RF-gated 3D CINE.

References: [1] Swingen, IJCI 2003. [2] Nezafat, JMRI, 2008. [3] Uribe, MRM, 2006.