# Respiratory Triggered Retrospectively Cardiac Gated Cine Steady-State Free Precession (SSFP) Imaging

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**Introduction:** Steady state free precession (SSFP) cine imaging is the method of choice for the evaluation of left ventricular function in cardiac cine MR studies due to its superior blood-to-muscle contrast, and higher intrinsic SNR. An essential requirement of SSFP sequences is the need for uninterrupted excitations to maintain the steady state (SS) as any interruption will entail additional preparatory period to achieve SS. As a result, in clinical practice, all cardiac cine SSFP sequences are acquired in a breathhold. Breathhold (BH) acquisitions, while fast, are limited to the breathholding capacity of the patient, and preclude application in patients with limited breathholding capability, e.g., sedated children. We propose a respiratory triggered (RT), segmented k-space SSFP sequence that can be driven to SS before the beginning of the cardiac gated (CG) data acquisition (DAQ). We hypothesize that this RTCG when combined with real-time respiratory slice tracking, will significantly minimize the deleterious effect of respiratory motion and could pave the way for a free breathing cine SSFP acquisition. The purpose of this work is to test the validity of this hypothesis.

**Materials and Methods:** All imaging was done on a commercial 1.5 T MR scanner (Achieva, Philips Healthcare). The stock cine SSFP sequence provided by the manufacturer was modified to include respiratory triggering and tracking with the ability to have a user-prescribed minimum duration for start-up excitations before the cardiac gated acquisition.

Phantom: An agarose gel phantom with relaxation parameters mimicking myocardium (T1 = 850ms, T2=45ms) was made. SSFP acquisitions were performed with various starup times to estimate the minimum duration required to bring the myocardial signal to SS.

Subjects: All subjects (n=5, 4m, age: 36±6 yrs) provided written informed consent.

MRI Acquisition: Conventional BHCG cine SSFP images in the short-axis orientation covering the entire left ventricle (LV) were acquired with the following parameters: TR/TE/flip angle: 3/1.5/60°; acquired voxel size: 1.5 x 1.5 x 8 $mm^3$; Sensitivity Encoding (SENSE) acceleration factor: 2; temporal resolution: 30-40 ms; imaging time : 8-9 RR intervals/slice. Identical imaging parameters were used for the RTCG acquisition. The start-up RF excitations commenced immediately after the respiratory trigger at the beginning of an expiration and continued for at least 400 ms (based on phantom studies), before looking for an R-top from the VCG. The DAQ commenced at the occurrence of the R-top with slice offset correction, and ended at the occurrence of the following R-top, and was processed by the real-time arrhythmia rejection algorithm.

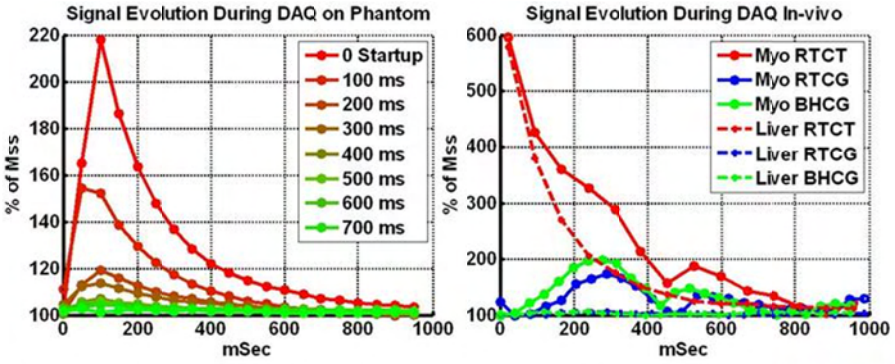


**Figure** : **(a)** Signal evolution in myocardium mimicking static phantom during the data acquisition after startup excitations of various durations. After 300ms startup excitations steady state is achieved. **(b)** In-vivo signal evolution during data acquisition for myocardial (solid lines) and liver (dotted lines) tissues with different acquisition techniques. Respiratory and cardiac triggered (RTCT, red) acquisition without any startup excitations shows that at least 400ms are required to attain the steady state. Both, breathhold cardiac gated (BHCG, green) acquisition with startup excitations for one cardiac cycle and respiratory triggered cardiac gated (RTCG, blue) acquisition with 400ms startup excitations show liver signal has achieved the desired steady state. The myocardial signal too is close to steady sate for both BHCG and RTCG acquisitions, however the longitudinal contraction of the myocardium brings fresh spins inside the excited slice causing elevated signal in systole. Signal elevation due to myocardial contraction is also seen in RTCT.

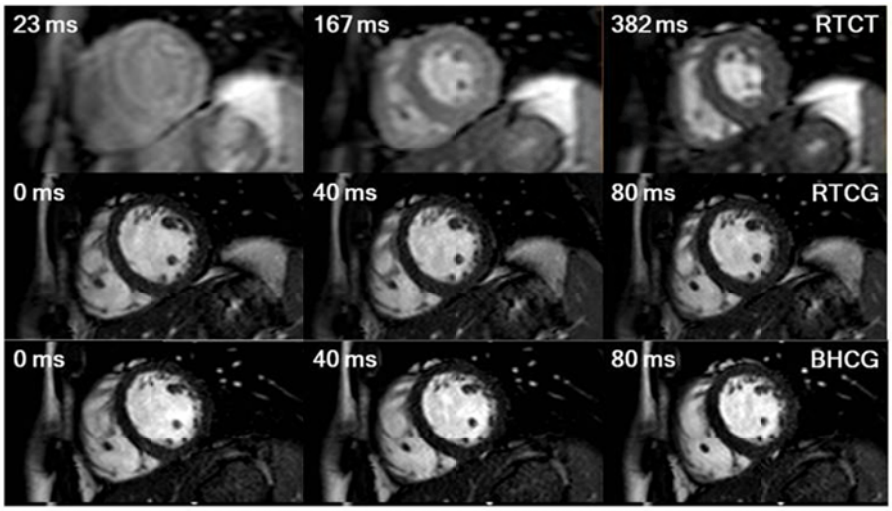


**Figure** : Cine SSFP images of Subject 3 with respiratory and cardiac triggered, respiratory trigged cardiac gated and breathhold cardiac gated acquisition techniques. The middle row depicts the successful drive to steady state signal in 400ms being used in the proposed RTCG segmented k-space cine SSFP acquisition.

**Results:** Phantom studies revealed that if the startup excitation duration is at least 400 ms, the percent variation of the MR signal from SS is less than 7% (Figure 1a). Representative images from Subject 3 (Figure 2) confirm the theoretical findings (Figure 1b). The LV volumes EDV and ESV estimated from the BH cine SSFP sequences was in close agreement with RTCG cine segmented k-space SSFP sequence with respiratory motion compensation.

**Discussion:** The elimination of the breath-hold constraint on a cine SSFP sequence can have significant impact on the following clinical areas: (a) evaluation of LV function in subjects with compromised respiratory capacity; (b) the ability to acquire high temporal resolution cine images necessary for the assessment of transient phenomena such as iso-volumic relaxation time etc. (c) the ability to acquire multi-phase, high-resolution anatomic images, e.g., coronary MR angiography etc. The strength of the RTCG approach is that the RF duty cycle typically remains about 50% and as a result, the SSFP sequence can be acquired over several minutes without SAR constraints even at high-fields.

**Conclusions:** The results from the study suggest that it is feasible to obtain diagnostic quality free breathing cardiac cine SSFP images using respiratory trigger and retrospective cardiac gating with a drive to steady state at each expiration phase. The free breathing approach releases the breath hold capability imposed time constraint allowing high spatial or temporal resolution cardiac cine imaging.