Prospective Self-Gating for Simultaneous Compensation of Cardiac and Respiratory Motion

J. Curcic[1], M. Buehrer[1], P. Boesiger[1], and S. Kozerke[1]
[1]Institute for Biomedical Engineering, ETH Zurich, Zurich, Switzerland

Introduction:
In cardiac imaging, self-gating principles may be applied for either cardiac triggering [1] or respiratory gating [2]. These methods simplify patient setup and scan planning as placement of physiological sensors and dedicated respiratory navigation methods become unnecessary. Also, since motion data are extracted from the imaging data themselves, motion information and actual object motion are potentially more consistent. So far, self-gating methods have been retrospective involving extended temporal coverage in acquisition to account for varying heart rates and to ensure a sufficient number of heart cycles acquired in the same respiratory state. Therefore, relatively low scan efficiencies are obtained relative to conventionally triggered techniques. In this work a prospective self-gating approach for time-efficient free breathing cardiac imaging is presented neither requiring an electrocardiogram (ECG) nor respiratory navigation. The motion data needed for synchronization are extracted and processed in real-time from repeatedly acquired data at k-space center. Image quality obtained with the proposed method was found to be comparable to the ECG triggered breathheld acquisitions while the scan efficiency was significantly increased.

Methods:
To repeatedly measure the k-space center a modified SSFP sequence [3] was implemented, providing a signal which contains both cardiac and respiratory synchronous variations (Figure 1). Cardiac variations arise from changes of the blood volume in the heart during the cardiac cycle. Respiratory-related variations stem from moving structures such as the liver or abdomen which shift in and out of the sensitive imaging volume during the respiratory cycle. Due to the local sensitivities of the coil elements it was found that some elements exhibit stronger cardiac variations while others provided better respiratory signal variations. This property was used to select the best elements for either cardiac triggering or respiratory gating. The best triggering signal was chosen by measuring the standard deviation between trigger times and selecting the coil with the lowest trigger variability. The best gating signal was chosen as the one having the most frequent occurrence of values above the predetermined threshold. All these calculations were performed prior to the scan in a short preparation period.
Since cardiac and respiratory signals are superimposed, real-time separation is necessary in order to use motion information prospectively. To this end, two efficient filters were designed complying with real-time requirements. A Butterworth band-pass filter extracts the cardiac related signal component followed by a peak-finding algorithm providing the cardiac trigger. For extracting the respiratory motion variation an adaptive averaging filter was implemented which uses the detected trigger-points to average over one cardiac cycle. In addition an adaptive threshold was implemented for definition of the respiratory gating window.
To test the feasibility of the approach a cardiac four-chamber view of a healthy volunteer was acquired (TR = 4.5ms, TE = 2.6ms, flip angle = 60°, scan matrix = 192x186, FOV = 320x320mm^2, slice thickness = 8mm, 11 lines/segment, 30 cardiac phases) using a five channel cardiac coil array. To asses the quality of the extracted self-gating motion curves, signals from an ECG and the respiratory belt were simultaneously acquired and stored. As reference a retrospective self-gating acquisition described in [4] was performed. In the retrospective approach the data are evaluated after the acquisition, therefore requiring temporal oversampling of the data to ensure that every profile is acquired at least once in an acceptable motion state. Additionally, a standard ECG triggered breathheld acquisition was acquired as second reference.

Results:
Cardiac and respiratory signal variations could be extracted in real-time and were comparable to the wired ECG and respiratory belt signals (Figure 2). The standard deviation between the wired ECG signal and the self-gating trigger was less than 11 msec. Reconstructed images were of comparable quality relative to the retrospective self-gated approach. At the same time, scan efficiency of the prospective method was significantly increased relative to the retrospective approach (prospective: 64 sec + 10 sec preparation period; retrospective: 160 sec). Both, the prospective and the retrospective methods compared well with the standard ECG, breathheld acquisition (Figure 3).

Discussion:
It has been shown that cardiac and respiratory variations can be accurately detected prospectively using signals originating from the k-space center and thereby eliminating the need for external cardiac and respiratory signal detection. Compared to the retrospective self-gating approach total scan time could be reduced while image quality was well maintained. Further studies are warranted to test the robustness in larger cohorts of volunteers and patients.

References:
[1] Larson A.C. et al. MRM 51:93-102 (2004)
[2] Larson A.C. et al. MRM 53:159-168 (2005)
[3] Crow M.E. et al. MRM 52:782-788 (2004)
[4] Buehrer M. et al. ESMRMB (2006):109

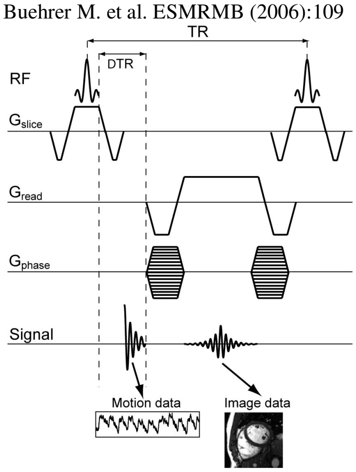

Figure 1: Modified SSFP sequence for self-gating. For motion data acquisition all gradients after the rephasing slice encoding gradient are shifted to record an FID, representing the k-space center.

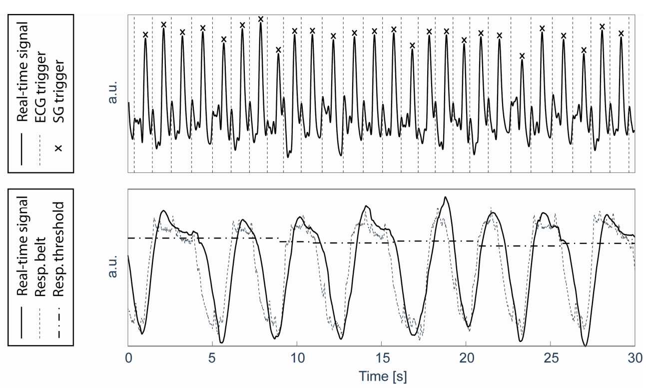

Figure 2: Filtered cardiac and respiratory motion signals obtained from the k-space center. Trigger points calculated from self-gating signals are marked with x. Dotted vertical lines represent ECG trigger points acquired for reference (upper panel). The respiratory trace obtained in real-time is compared to respiratory belt signal (lower panel). Note that the respiratory signal exhibits a shift due to the averaging filter. Additionally the adaptive threshold used for gating is shown as slash dotted line.

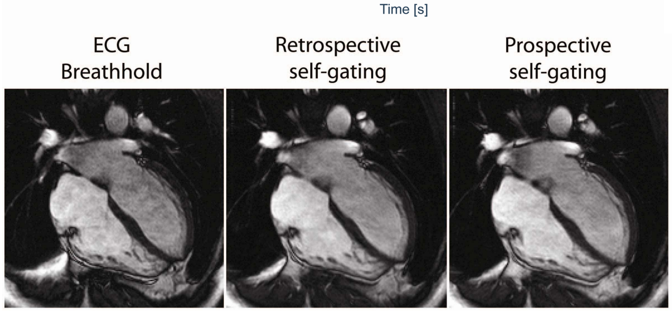

Figure 3: Images from a cardiac four chamber view. A standard ECG triggered breath-hold acquisition (left) is compared to retrospective self-gating (middle) and the prospective self-gating method (right).