A New Approach to Respiratory Motion Compensation for Steady-state Free Precession Cine Imaging

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Introduction: Accurate surveillance of the ventricular function is an essential part of noninvasive cardiovascular magnetic resonance (CMR) [1]. Evaluation of ventricular size and function is typically performed using a retrospectively ECG-gated segmented *k*-space steady-state free precession (SSFP) cine acquisition with multiple breath-holds [2]. However, ill or sedated patients, and young children are often unable to breath-hold (BH). A common alternative is to reduce respiratory motion artifact by performing the acquisition with multiple signal averages (AVG), but this approach may yield inconsistent, blurred image quality that hinders accurate assessment. Therefore, we aimed to develop a new method termed NaviGate for free-breathing imaging that uses a pencil-beam navigator (NAV) to minimize the respiratory motion artifact yet 1) maintains the equilibrium state of the SSFP acquisition, 2) samples the entire cardiac cycle, and 3) yields image quality comparable to the BH approach.

Materials and Methods: A schematic diagram of the proposed method and different steps of the algorithm are shown in Figs. 1 and 2, respectively. Three pencil-beam NAVs are performed during each beat to monitor the position of the right hemi-diaphragm (RHD). If the RHD location at NAV3 is within the acceptance window and is greater than that of NAV2 (i.e., transition from inspiration to expiration), the next beat is used for data acquisition. NAV1 is then performed at the conclusion of that beat, and, if it is within the acceptance window, the acquired data is accepted for the image reconstruction. Otherwise, the data is rejected and NAV3 is assessed again on the next beat.

To demonstrate the feasibility of NaviGate, 5 adult patients (2 males, 32±11 years) were prospectively studied with their informed consent. On a 1.5T MR scanner (Philips Achieva) with a 32 element coil, cine acquisitions were performed using a *k*-space segmented SSFP sequence with a FOV 260×260 mm^2, voxel size 1-2×1-2×8 mm^3, TR/TE/α 2.9/1.47/45°, heart phases 30, phase percentage 67, SENSE factor 2, and NAV acceptance window 8 mm. In each patient, 3 sets of SSFP cine images were acquired in a random order: 1) breath-hold (BH); 2) free-breathing with 3 averages (3AVG); and 3) free-breathing with NaviGate. All 3 datasets were analyzed by an experienced physician to measure left and right ventricular end-diastolic and end-systolic volumes (EDV and ESV). Sharpness of the endocardial borders was scored by the physician blinded to the technique according to a 4 point-scale: 1-poor; 4-excellent. A paired two-tailed Student's t-test was used for the statistical analysis and a *p*-value ≤0.05 was considered statistically significant.

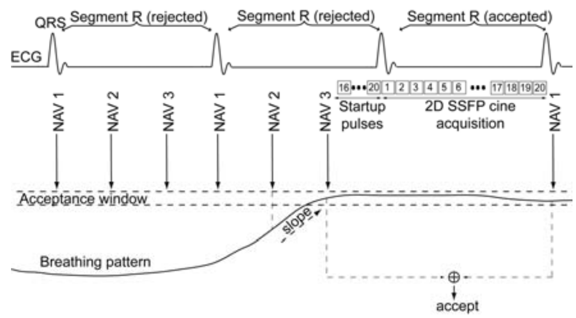

Fig. 1: *Schematic diagram of the proposed respiratory motion compensation method (NaviGate) for a free-breathing cine SSFP sequence.*

1. Apply NAV 1 at the end of RR interval when QRS is detected
2. Apply NAV 2 at the 40% RR interval
3. Apply NAV 3 at the 80% of RR interval
4. Keep acquiring NAV 1, NAV 2, and NAV 3, if
    a. NAV 3 was rejected or
    b. NAV 3 was lower than NAV 2 (moving toward inspiration)
5. Acquire SSFP cine data without any NAVs in the next beat if
    a. NAV 3 was accepted and
    b. NAV 3 was greater than NAV 2 (moving toward expiration)
6. Accept the acquired data in the next beat if
    a. NAV1 is accepted
    b. No arrythmia is detected

Fig. 2: *NaviGate algorithm.*

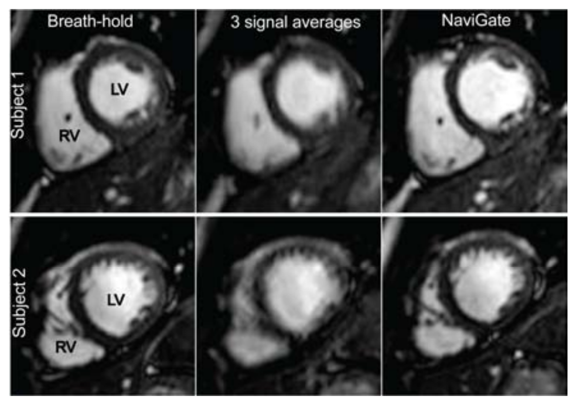

Fig. 3: *A short-axis mid-ventricular slice in two subjects acquired with breath-hold, free-breathing with 3 signal averages, and NaviGate.*

Results: Fig. 3 shows the images acquired with NaviGate, BH, and 3AVG in a mid-ventricular slice from 2 subjects. The subjective sharpness of NaviGate (3.7±0.4) was superior to 3AVG (2.1±0.5, *p*<0.01) and comparable to the BH (4.0±0.0, *p*=0.2). EDV and ESV by NaviGate was not significantly different compared to BH but was different from 3AVG for the right ventricle (Table 1). Mean scan times (min) were 3.7±2.2 for BH, 3.5±0.6 for 3AVG, and 5.3±0.7 for NaviGate.

Method	Mean difference ± standard deviation (ml)							
	Left Ventricle				Right Ventricle			
	EDV	*p*	ESV	*p*	EDV	*p*	ESV	*p*
NaviGate vs. BH	5±8	0.25	3±4	0.26	-5±5	0.09	-2±3	0.25
NaviGate vs. 3AVG	-5±6	0.10	-2±2	0.08	-9±2	**<0.02**	-4±2	**<0.05**
BH vs. 3AVG	-10±4	**<0.02**	-5±3	**<0.02**	-4±5	0.19	-2±2	**<0.05**

Table 1: *Mean difference of the end-diastolic volume (EDV) and end-systolic volume (ESV) of the right and left ventricles measured from the cine images acquired during breath-hold (BH), free-breathing with 3 averages (3AVG), and NaviGate.*

Conclusions: We developed and assessed a new respiratory navigator-based motion compensation method for free-breathing cine SSFP acquisition that has image quality that is superior to 3 signal averages and comparable to breath-hold acquisitions. Future work will assess this approach in a larger patient group of children and adults, and extend it to 3D cine acquisitions.

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References: [1] Semelka, Radiology, 1990; [2] Dehmer, Am J Cardio,1980.