Non-Cartesian Retrospective Reconstruction of Cardiac Motion in Patients with Severe Arrhythmia

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Target Audience: Physicians and scientists interested in the development of rapid imaging methods for patients with cardiovascular arrhythmias.

Introduction: Cardiovascular magnetic resonance imaging (MRI) is the gold standard for assessment of cardiac function but image quality is compromised in patients with severe arrhythmias. Recent real-time MRI methods are robust and can provide high quality images to remedy this situation, but it is recognized that multishot or segmented data acquisition would provide better spatial and temporal resolution (1–3). Nevertheless ECG-gated cine MRI can fail despite arrhythmia rejection (AR), as is shown in detail in Fig. 1. Our objective was to develop a retrospective reconstruction method using cardiac self-gating for patients with severe arrhythmias. Self-gated myocardial systolic and diastolic motion was determined from low-resolution golden angle radial data and then the same golden angle dataset was retrospectively reconstructed to obtain high quality images. The effectiveness of the method to image normal and ectopic rhythms was evaluated in patients with severe ventricular arrhythmia.

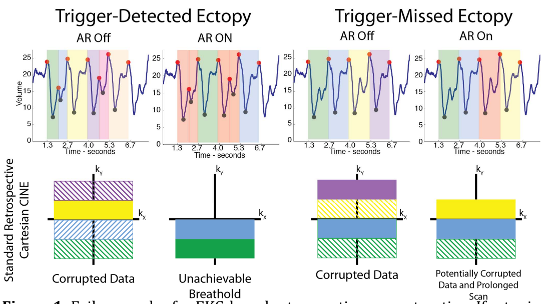

Figure 1: Failure modes for EKG-based retrospective reconstruction. If ectopic beats are detected by the trigger mechanism, there are two possible outcomes. If AR is off, then the ectopic beats will be incorrectly scaled to the desired RR duration leading to corrupt imaging data (crosshatch pattern). If AR is on, data will be rejected leading to prolonged scan times. If the ectopic beats go undetected, k-space data will be acquired during the ectopic beats and either be scaled, rejected, or a combination leading to imaging artifacts.

Methods: Retrospective Cartesian CINE with arrhythmia rejection and non-gated golden angle radial projections were acquired in 2 patients with frequent ectopic beats on a 1.5 T clinical imaging system (Avanto, Siemens Healthcare, Erlangen, Germany) equipped with nominal 40 mT/m magnetic field gradients. Cine data was obtained using a 2D, breathheld, multislice, retrospectively-gated, cine balanced steady-state free-precession sequence with the following imaging parameters, TE = 1.16 ms, TR = 2.32 ms, matrix = 192 x 156, field-of-view = 340 mm x 276 mm, BW = 930 Hz/pixel, phases = 19, slices = 12, slice thickness = 8 mm, slice spacing = 10 mm and temporal resolution = 35.6 ms. Real-time data was obtained using a golden angle radial trajectory and the following imaging parameters, TE = 1.4 ms, TR = 2.8 ms, number of radial k-space data = 128, FOV = 340 mm x 340 mm, bandwidth = 1184 Hz/pixel and k-space sampling according to the golden angle $\Phi \approx 111.25°$ (4). Imaging was performed in the short axis of the left ventricle over the same volume as CINE. The proposed retrospective reconstruction algorithm is illustrated in Figure 2. First, coil sensitivity maps (for SENSE reconstruction) are obtained from temporal average images (5). A low spatial resolution dataset is reconstructed using non-Cartesian SENSE with 50 radial projections per image frame. The ventricular volume in each image is measured via a level-set based segmentation technique (ITK-SNAP, Philadelphia, PA) to obtain a gating signal. The use of volume allows for normal and ectopic systolic events to be observed. Non-linear heart beat duration correction was applied to generate a retrospective dataset (6). Since end-systole can be observed, data just prior to an ectopic beat can be utilized without assumptions about beat duration.

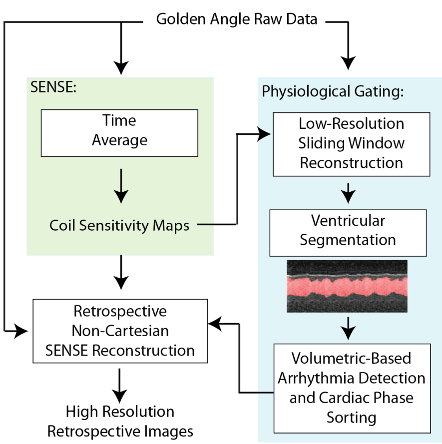

Figure 2: Proposed Reconstruction Technique. Golden angle data is used to generate coil sensitivity maps as well as low spatial resolution images. Segmentation results in a volume signal which allows for arrhythmia detection and cardiac phase sorting.

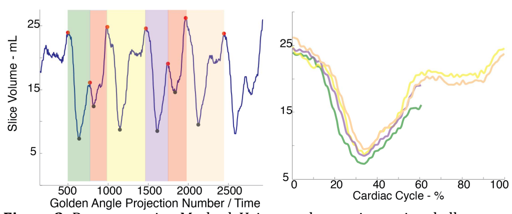

Figure 3: Reconstruction Method. Using a volume trigger signal allows for detection of end-systolic and diastolic events. The left panel shows two ectopic beats (red shading), 2 normal beats (yellow and tan), and two interrupted beats (green and purple). The proposed algorithm utilizes data from normal and interrupted beats to improve sampling and image quality. The right panel illustrates the retrospective sorting of the volume curve.

Results: Volumetric data are shown from one patient and one slice with severe cardiovascular arrhythmia. Figure 3 illustrates the proposed gating scheme. The volume curve allows for the observation of systolic and diastolic events. Therefore, k-space samples do not need to be 'rejected' until the ectopic beat occurs. As a result, more accurate and efficient retrospective reconstruction can be performed. For this patient, data from all four beats is utilized to obtain high resolution images (Figure 4). In the two uninterrupted beats, the entire cardiac cycle is incorporated into the registration. For the beats interrupted by ectopy, the samples prior to the ectopic beat can be utilized for the retrospective reconstruction.

Discussion: The proposed reconstruction algorithm improves upon some of the limitations of EKG-based techniques. Namely, segmentation of low-resolution images allows for identification of systolic and diastolic periods (both normal and ectopic). This volume-based approach allows for more efficient scanning (less discarded data). Retrospective sorting of the golden angle radial trajectory results in interleaving of golden angle acquisitions. Although this does not maintain the near-uniform sampling trajectory associated with golden angle acquisitions, the increased number of projections decreases undersampling and improves image quality. Ectopic contractions decrease the preload for subsequent beats. As a result, post-ectopic contractions are slightly different than beats prior to the ectopy. This method allows for the small changes between normal, ectopic, and post-ectopic contractions to be observed via slice volume and may allow for better cardiac phase sorting, arrhythmia rejection, and hemodynamic evaluation.

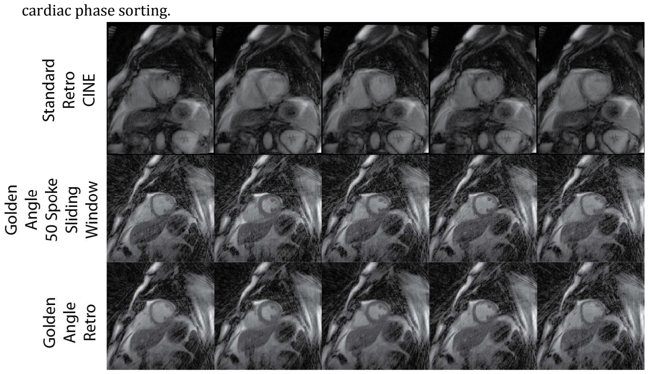

Figure 4: Reconstruction Results. First Row: Standard arrhythmia corrupted images. Second Row: 50 Spoke low-resolution images for segmentation. Third Row: Proposed retrospective reconstructed golden angle data.

References: 1. Larson AC MRM. 2004 Jan; 51(1):93–102. 2. Hansen MS. MRM. 2011 Dec 21; 000(3):1–10. 3. Kellman P. MRM. 2008 Apr; 59(4):771–8. 4. Winkelmann S. IEEE TMI. 2007 Jan;26(1):68–76. 5. Pruessmann KP. MRM. 2001;651:638–51. 6. Feinstein J. JMRI. 1997;7(5):794–8.