ECG/Navigator-Free 4D Whole-Heart Coronary MRA with Simultaneous Visualization of Cardiac Function and Anatomy

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Purpose: Cardiac and respiratory motion artifacts are major challenges in cardiac MRI, and are conventionally suppressed by prospective ECG and diaphragm navigator gating, respectively. However, these approaches require time-consuming setup and prolonged acquisition times, and are susceptible to variations of heart rate or respiratory pattern. Further, they can become unreliable at higher field strengths [1]. In this work, we propose to address these limitations by using retrospective self-gating (SG) with continuous 3D radial acquisition. The proposed method offers cardiac phase resolved whole-heart visualization in high isotropic spatial resolution and flexible temporal resolution, providing functional and anatomical information simultaneously. Here we demonstrate and discuss our initial healthy volunteer results in cine and coronary applications.

Methods: We used a spoiled gradient-echo sequence with Gd-BOPTA contrast-enhancement on a Siemens 3T scanner: TR/TE = 5.5/3.0ms, water-selective hard pulse, FOV=$(400\text{mm})^3$, matrix=384^3, flip angle=15°, and a 3D radial trajectory with 2D golden means ordering [2]. Imaging was performed continuously without any prospective gating or prep-pulses. Superior-inferior SG projections were inserted every 15 imaging lines. A total of 100,000 projections were collected with a fixed free-breathing scan time of ~10 minutes. In the offline reconstruction, we firstly extract the cardiac and respiratory motion signals from the SG profiles by principal component analysis. We then find the cardiac triggers by valley detection, reject the arrhythmic heartbeats, and bin the data into 9 cardiac and 6 respiratory phases. We subsequently perform respiratory motion correction separately for each cardiac phase to combine all respiratory phases [3], and reconstruct the 4D image series using a self-calibrating CG-SENSE method [4].

Results and Discussions: Shown in Fig. 1, the SG profiles displayed intensity variations from both cardiac and respiratory motion. The extracted motion signal showed excellent correspondence with the ECG and respiratory bellow waveforms. Fig. 2 shows the two reconstruction modes. In the performance-driven mode, the data was re-binned into 16 cardiac phases without view sharing. Each phase contained ~6,000 projections with a temporal footprint of ~50ms. The isotropic spatial resolution enabled arbitrary 3D reformatting. In the quality-driven mode, the quiescent window, which may span more than one cardiac phase (2 in this particular case), was retrospectively determined from the 4D image series. The image quality can therefore be improved by including more data into the reconstruction. The location and size of this acquisition window was automatically adjusted on a beat-by-beat basis to account for moderate heart rate variations. In this subject, the retrospective triggering showed improved RCA visualization than that from the simulated prospective triggering with a fixed trigger delay.

Conclusion: We have demonstrated the feasibility of a fully self-gated 4D whole-heart imaging technique with high isotropic spatial resolution and near 100% imaging efficiency through respiratory motion correction and retrospective cardiac self-gating. No ECG or diaphragm navigator is needed. The 4D visualization allows flexible reconstructions that prioritize either temporal resolution or image quality. Future efforts will be focused on optimizing the pulse sequence and reconstruction parameters, as well as comparing the dual-mode reconstruction with existing cardiac cine and coronary MRA protocols.

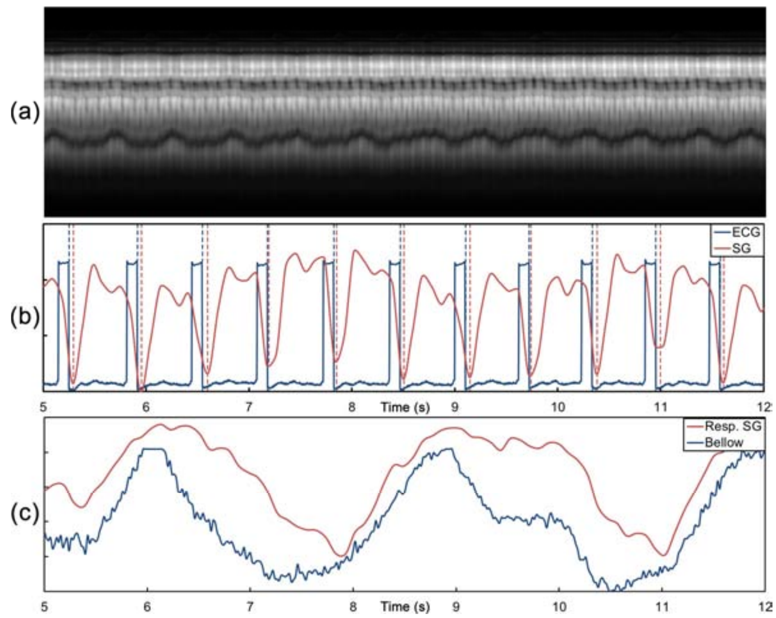

Figure 1: (a) A typical SG profile with intensity variations from cardiac and respiratory motion. (b) Cardiac SG signal shows excellent correspondence with ECG. (c) Likewise for respiratory SG and respiratory bellow signal.

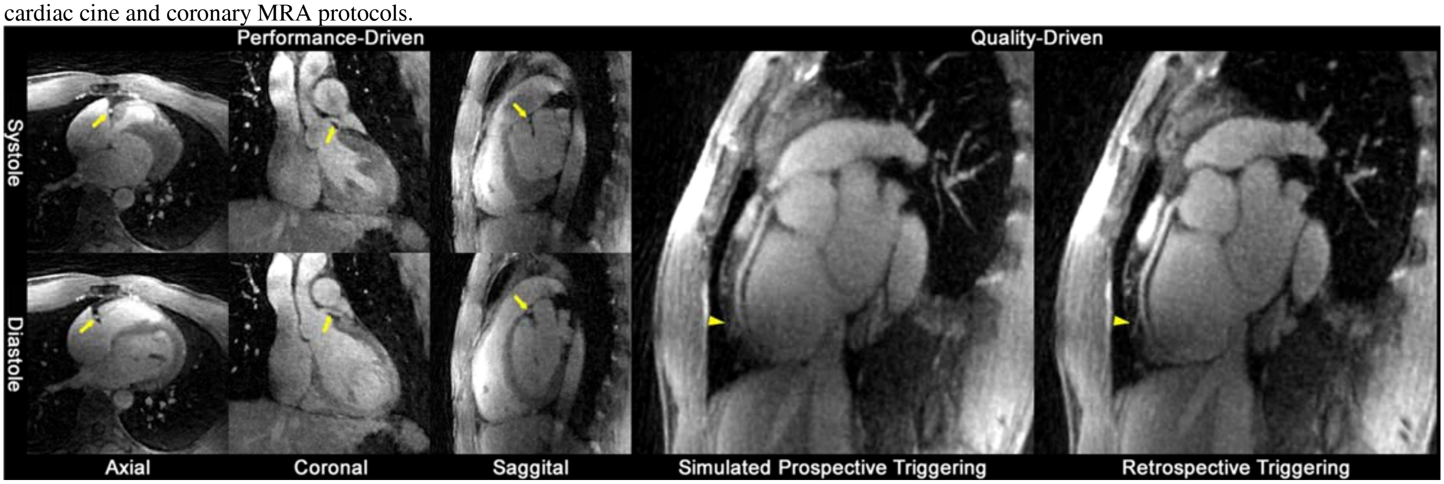

Figure 2: Left: The late-systole and mid-diastole phases in axial, coronal and sagittal orientations. Coronary arteries are clearly visible (arrows). Right: retrospective triggering resulted in better RCA visualization (arrowheads) compared with using a fixed trigger delay in simulated prospective triggering.

References: [1] Stuber M. et al. MRM 2002 48:425–429. [2] Chan R.W. et al. MRM 2009 61:354–363. [3] Pang J. et al. MRM 2013 doi:10.1002/mrm.24628. [4] Pang J. et al. ISMRM 2013 (1295).