Prospective Respiratory Navigator Gated RF Excitation in Whole-heart Coronary MRA at 3T

J. Yu[1,2], M. Schär[2,3], H. Agarwal[2,4], and M. Stuber[2,5]
[1]Department of Biomedical Engineering, Johns Hopkins University, Baltimore, Maryland, United States, [2]Russell H. Morgan Department of Radiology and Radiological Science, Johns Hopkins University, Baltimore, Maryland, United States, [3]Philips Healthcare, Cleveland, Ohio, United States, [4]Department of Electrical and Computer Engineering, John Hopkins University, Baltimore, Maryland, United States, [5]Department of Radiology, University Hospital Center and University of Lausanne (CHUV), Lausanne, VD, Switzerland

Introduction: Contemporary coronary magnetic resonance angiography (MRA) at 3T suffers from signal-to-noise ratio (SNR) constraints inherent to the most commonly used spoiled gradient echo imaging sequence. Particularly for whole-heart coronary MRA [1], the large amount of data and constraints related to scan time necessitate a relatively long train of radiofrequency (RF) excitations during each heartbeat. However, and in combination with prolonged blood T1 at higher magnetic field strength, this long RF excitation train reduces the magnetization available for imaging in the subsequent cardiac cycle, and therefore overall SNR.

The goal of this work was to improve the blood-pool SNR in prospective respiratory navigator gated and corrected whole-heart coronary MRA. For most of the contemporary navigator implementations, RF excitations for imaging are always performed, independent of the navigator-detected lung-liver interface position being inside or outside the gating window. For positions outside the gating window, the data are still collected but are simply discarded during reconstruction. Using this approach, the steady-state magnetization is kept relatively constant - at the expense of its magnitude, however. To obtain more signal, we propose a method that selectively suspends RF excitations in the gradient echo read-out train in real-time if the navigator-detected lung-liver interface position is identified outside the gating window (navigator gated RF excitation).

Methods: While the navigator gated RF excitation may allow for more signal, the steady-state magnetization is no longer identical for each heartbeat and unwanted signal variations in *k*-space may occur. There are two sources of signal inconsistency in *k*-space: first, the signal decay within the RF pulse train with a constant flip angle (intra-heartbeat), and secondly the variation of the steady-state magnetization that depends on the navigator gated RF excitation during preceding heart-beats (inter-heartbeat). The former part has successfully been addressed in 3D coronary MRA by utilizing a concentric elliptical *k*-space ordering, as shown in Fig 1a. The different colors of ellipsoids visualize the sequential ordering of profiles in *k*-space that originate from RF excitations within each heartbeat. For the latter part, the conventionally filled *k*-space will have the profiles acquired with higher (white) and with lower (grey) steady-state signal in a random looking pattern (Fig 1b), which potentially has a negative effect on SNR. With the proposed methodology, phase encoding is reordered based on the real-time respiratory navigator gating decision, so that increased signal is deposited in the center of *k*-space to maximize SNR and, furthermore, high intensity profiles are placed adjacent to each other in *k*-space (Fig 1c). As a result, regional signal variations in *k*-space can be minimized. Note that this reordering process shuffles the *k*-space lines within one color of the ellipsoid (inter-heartbeat) in Fig 1a rather than across ellipsoids of different colors (intra-heartbeat). Therefore, the concentric elliptical *k*-space order remains unaffected.

The SNR performance of this proposed methodology was simulated numerically and the results were compared to those from a conventional method with RF excitation constantly performed (baseline). For both examples, respiratory navigator gating signal measured in one volunteer was applied in the simulation. The proposed methodology was implemented on a 3T MR whole body system (Philips Healthcare, Best, The Netherlands) equipped with a 32 channel cardiac surface coil. Whole-heart coronary MRA with the new technique and with the baseline method were acquired *in vivo* in 3 healthy adult subjects. Both sequences had identical imaging parameters: TR/TE = 3.3/1.1ms, acquisition window = 60-110ms, flip angle = 20°, acquired voxel = 1.3mm isotropic, and echo time for T2prep [2] was 50ms. On the resultant magnitude images, blood-pool SNR and blood-myocardium contrast-to-noise ratio (CNR) were quantified [3].

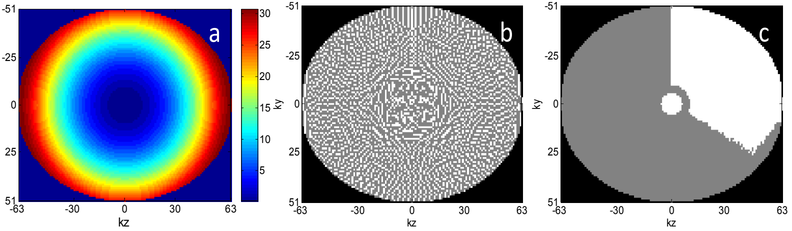

Figure 1. *Illustration of profile filling order in k-space for whole-heart 3D coronary MRA. (a) For the concentric elliptical filling order, dark blue profiles in the center are acquired first during one heart-beat while dark red profiles are acquired at the end of the same heartbeat. An angular increment is performed for subsequent heartbeats. (b) Using the conventional profile filling order in k-space in conjunction with the prospective navigator gated RF excitation, high (white) and low (grey) signal intensity profiles are randomly distributed in k-space. With the proposed reordering method (c), profiles of high steady-state signal are grouped together to maximize SNR and minimize unwanted image artifacts.*

Results: With a gating efficiency of 67%, the numerical simulation of the new technique yielded a SNR gain of 27% for blood when compared to the baseline approach. I*n vivo*, an average 35% improvement in blood-pool SNR (57.3±20.4 vs. 42.2±13.2 from baseline) and a 50% improvement in blood-myocardium CNR (34.0±13.2 vs. 22.5±7.6 from baseline) were measured with an average gating efficiency of 55±5% for the proposed method. The multiplanar reformatted images of left anterior descending (LAD), left circumflex (LCX) and right coronary artery (RCA) are displayed in Fig 2. The depiction of mid and distal segments of the vessels was improved (see arrows) with the prospective respiratory navigator gated RF excitation method.

Discussion: Preliminary data obtained *in vivo* suggest feasibility of real-time prospective navigator gated RF excitation with modified *k*-space profile ordering for improving blood-pool SNR, without compromising scanning time or spatial resolution. However, the magnitude of the SNR enhancement will depend on the breathing pattern, its regularity and the resultant navigator efficiency. Future investigation of *k*-space profile ordering in conjunction with weighting functions [4] may help to further minimize signal variation and improve image quality.

References: 1. Weber OM, et al., MRM 2003: 50(6):1223-8; 2. Nezafat R, et al., MRM 2006: 55(4): 858-64; 3. Yu J, et al., MRM 2009: 62(5): 1211-20; 4. Huber M, et al., MRM 2001: 45(4): 645-52. **Acknowledgement:** NIH RO1 HL084186.

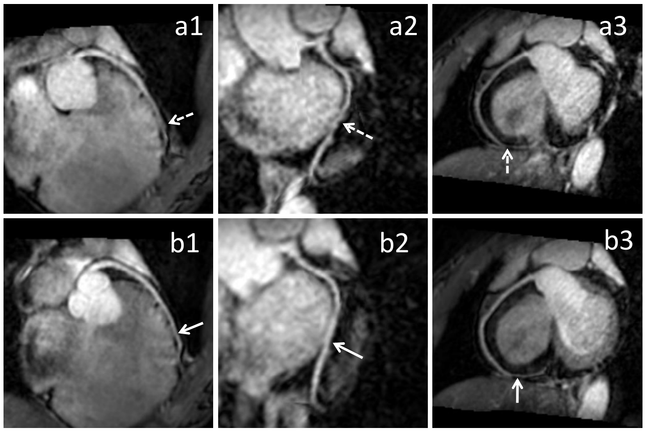

Figure 2. *Reformatted images of the LAD (a1, b1), the LCX (a2, b2) and the RCA (a3, b3) are displayed for the conventional baseline method (top row) and the prospective respiratory navigator gated RF excitation technique (bottom row). Compared to the baseline, the proposed methodology leads to both higher visual blood -pool SNR and better vessel conspicuity (arrows).*