Non-ECG triggered, self-navigated 3D radial whole heart MRI with golden angle for multiphase coronary imaging.

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Target Audience: Basic researchers interested in cardiovascular and coronary imaging.

Purpose: In recent years ECG triggered 3D self-navigated techniques have significantly improved the ease-of-use and time efficiency of whole heart coronary MRI acquisitions [1,3] when compared to conventional navigator techniques. Despite this improved efficiency, and provided that image data collection is typically performed during a small acquisition window in mid-diastole, the ratio of effective data sampling to the total scan time (sampling efficiency) remains lower than 4%. The sampling efficiency can be significantly improved by acquiring multiple self-navigated 3D whole heart images during the cardiac cycle (4D imaging). Indeed, powerful 4D imaging techniques have already been implemented and their utility explored [4,6]. However, datasets with anisotropic spatial resolution were acquired and limited spatial or temporal coverage was reported. To try to push the limits of self navigation, we propose the implementation of a non-ECG triggered radial 3D multiphase whole-heart technique with isotropic spatial resolution and uniform temporal coverage of the entire cardiac cycle. This technique builds on the previously reported 3D radial trajectory implementing the spiral phyllotaxis pattern [7]. In the present approach, data acquisition is performed continuously, non-triggered, and during free-breathing. The ECG signal is recorded during the acquisition period and used offline for retrospective binning of the k-space segments into multiple volumes as a function of their acquisition time within the R-R interval. Simultaneously, the algorithm for respiratory self-navigation described in [2] is applied to compensate for respiratory motion. First in vivo results obtained in human subjects are discussed.

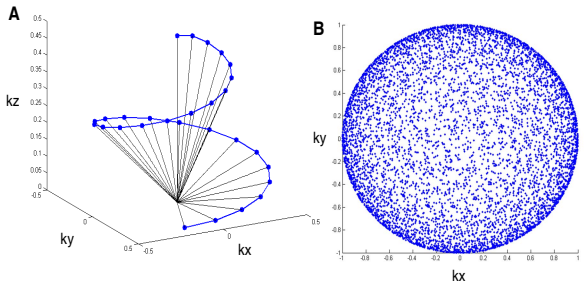

Figure 1: (A) Top hemisphere of readout lines in k-space for one segment, (black lines), and starting point of each readout (blue dots). (B) Example of the uniform distribution of the readouts within one bin (view from above).

Methods: The proposed technique was implemented on a 1.5T clinical MRI scanner (Aera, Siemens AG, Healthcare Sector, Erlangen, Germany) equipped with a total of 30 receiver coil elements and tested in three healthy adult subjects. Three-dimensional multiphase whole-heart imaging was performed with the following parameters: TR/TE = 3.1/1.56ms, FOV = $(220mm)^3$, acquired voxel size = $(1.15mm)^3$, matrix size = 192^3, radiofrequency excitation angle = 70°.The imaging part of the sequence consists of a radial segmented k-space acquisition and each segment is preceded by both a T_2 preparation (TE T_2Prep= 40 ms) and fat saturation pulse. The acquisition window was 86.8 ms with 28 radial readouts per k-space segment (Fig.1.A). A total of 65604 k-space lines were acquired and the ECG was recorded simultaneously, but was not used for triggering. Preparation pulses and data acquisition are continuously repeated without interrupt during a total duration of 7:32 min during free breathing. Offline and after the scan, the acquired segments are aligned with the ECG and regrouped in 10 different bins as a function of their position in the R-R interval. As the spiral phyllotaxis pattern [7] features an intrinsic rotation of subsequently acquired k-space segments (Fig 1,A) by the golden angle (137.51°), a good sampling uniformity over time is automatically obtained and the same point in k-space is never re-acquired. On average, each of the 10 acquired 3D volumes consisted of 230±16 k-space segments (6440±460 radial readouts), corresponding to an under sampling ratio of 10% with respect to the Nyquist limit. Self-navigation for respiratory motion correction [2] was then individually applied to each of the ten 3D volumes.

Results and Discussions: Scans were successfully completed in all volunteers and a total of 4GB of raw data were acquired for each 4D dataset. Due to the spiral phyllotaxis trajectory, a rather uniform sampling of k-space (Fig1.B) was intrinsically obtained for each volume. Reformatting with isotropic spatial resolution in any 3D orientation was feasible for all time points in the cardiac cycle. In Fig.2, selected axial (top row) and coronal (bottom row) views from two out of the ten 3D volumes acquired in one volunteer, are displayed. In Fig.2.A and C, systolic images are shown while diastolic reformats are visualized in Fig.2B and D. A segment of the right coronary artery (RCA) can be identified in different views both at end systole (arrow A,C) and in mid diastole (arrow B,D). In general, the fat signal surrounding the RCA as well as the myocardial signal is suppressed because of the pre-pulses (fat saturation and T_2Prep) that are integrated as part of the free-running sequence. However, when compared to earlier 3D self-navigated whole heart approaches, the present implementation does not lead to extra costs in scanning time despite an improvement in sampling efficiency from 3.7% to 16%. This affords the advantage that more information per unit time is obtained. Nevertheless, future efforts are directed toward the evaluation of pre-pulse strategies that maintain contrast while simultaneously ameliorate the temporal resolution, and toward an improved under sampling ratio relative to the Nyquist limit.

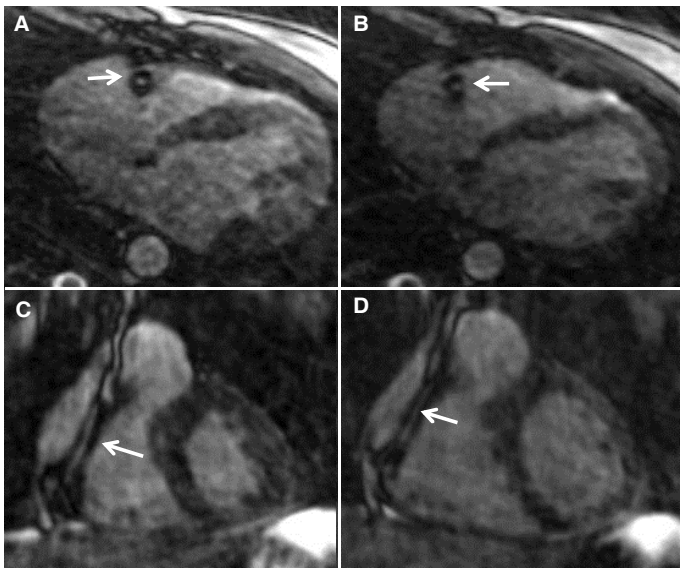

Figure 2: Multiplanar reformats extracted from two (out of 10) different time points in the cardiac cycle: left column (A,C) systole; right column (B,D) diastole. Top row (A,B) axial view of the heart where a cross-section of the RCA is visible (arrow); Bottom row (C,D) respective coronal view that displays a segment of the RCA (arrow).

Conclusions: Non-ECG triggered self-navigated 3D radial multiphase free-breathing whole heart coronary imaging with isotropic spatial resolution was successfully implemented and tested in vivo for the first time. Although temporal resolution and image quality still need to be improved, this technique represents the first step toward a whole-heart 3D coronary MRA approach in which the time frame with the best depiction of any given coronary artery segment can be freely selected.

References: **1.**Stehning et al. MRM. 2005,54(2):476-80; **2.**Piccini et al. MRM 2012, 68(2) :571-9; **3.**Lai et al. JMRI. 2008 28(3):612-20; **4.**Lai et al. MRM 2008,59:1378–1385; **5.**Spincemaille et al. MRI 2011,29(6):861-8; **6.**Wu HH, Gurney PT, Hu BS, Nishimura DG, McConnell MV, MRM may 2012; **7.**Piccini et al. MRM 2011 66(4):1049-56.