Initial Experience in Patients for Highly Accelerated Free-Breathing Whole-Heart Coronary MRA

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INTRODUCTION – 3D whole-heart coronary magnetic resonance angiography (CMRA) allows the assessment of the complete cardiac anatomy including the coronary arteries within one single scan. In this context, respiratory motion remains a major challenge leading to motion-blur in the resulting images. Commonly, these artifacts are avoided by prospectively gating the acquisition to end-expiration with a navigator [1,2]. However, acceptance rates typically less than 40% lead to prolonged total acquisition times. Beside techniques improving respiratory motion compensation [3,4,5], the overall scan time can also be reduced by accelerated data acquisition, e.g. using parallel imaging and compressed sensing. In this context, a method has been introduced to CMRA utilizing the Cartesian spiral phyllotaxis sampling pattern and iterative reconstruction, and promising results were shown in volunteers [6]. The highly accelerated data acquisition of this method facilitates its integration into a clinical examination, e.g. between perfusion and delayed-gadolinium-enhancement imaging. The aim of this work was to evaluate the image quality and diagnostic performance of accelerated CMRA on patients within a routine clinical cardiac exam.

MATERIALS and METHODS – Accelerated CMRA was performed in a total of 15 patients (8 men, mean age 60.7±15.4 years) on a 3T clinical MR scanner (MAGNETOM Skyra, Siemens AG, Healthcare, Erlangen, Germany) using a prototype sequence described in [6]. While the spiral phyllotaxis pattern was utilized for an incoherent sub-sampling of the Cartesian phase-encoding plane, the sequential order of the readouts was adapted prior to data acquisition to achieve a linear reordering in k-space.T2-prepared, fat-saturated, ECG-gated, 3D volume-selective GRE imaging was performed in sagittal slice orientation with the following parameters: TR/TE 4.0/2.0 ms, $\alpha = 20°$, FOV 270×250×138 mm^3, matrix 240×222×120, voxel size $(1.15\ mm)^3$ and a receiver bandwidth of 400 Hz/Px. The navigator acceptance window with a width of 5 mm was placed in end-expiration and slice tracking was activated. Signal reception was performed using the body matrix coil and the spine matrix coil. Data acquisition was adjusted to the patient-specific coronary resting phase (80-100 ms), but the acceleration factor was fixed to 10.2 in all subjects. The scan time was 2:22 min considering 100% navigator efficiency and a heart rate of 60 bpm. In most cases, data were acquired between the perfusion and the delayed-enhancement scan. Image reconstruction was fully integrated on the scanner and performed with a regularized SENSE-type iterative reconstruction as described in [7]. For all datasets, the regularization parameter was fixed to 0.003 and image reconstruction was terminated after 20 iterations of the mFISTA algorithm. Image quality was quantitatively assessed in all CMRA and CTA datasets using apparent vessel length. In addition, in cases where CTA was available (6 cases), the depiction of the proximal, mid, and distal segments of the right coronary artery (RCA) and left anterior descending artery (LAD) were visually graded by a cardiologist with experience in MR and CT according to [8]. In this score, segments with a grade >0 were considered as detectable and 4 represents sharply defined coronary arteries.

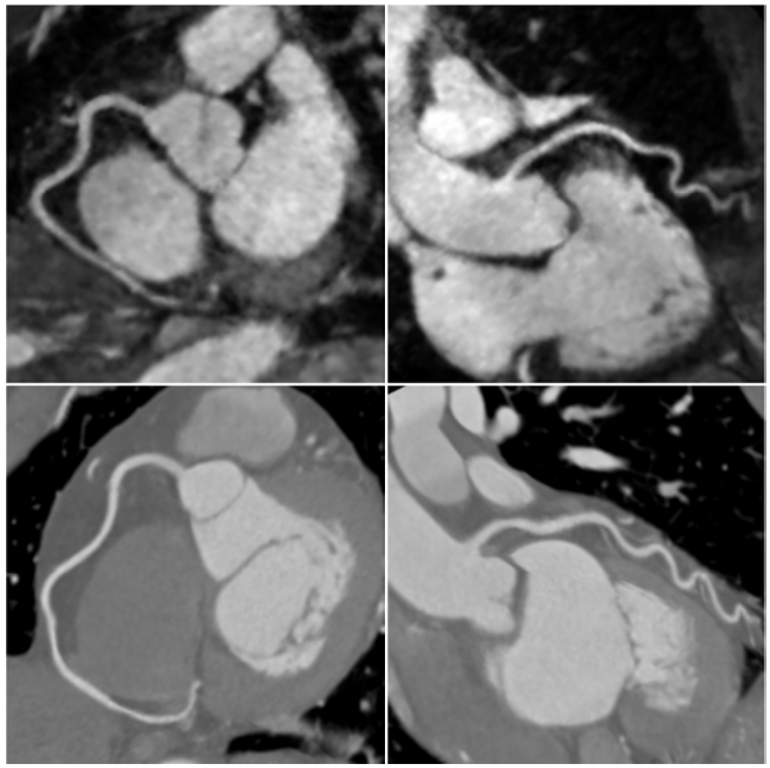

Figure 1: Multi-planar reformats of the RCA (left column) and LAD (right column) of one representative patient obtained from CMRA (top row) and CTA (bottom row).

		Vessel Length [mm]	Visual Score [8]		
			Proximal	Mid	Distal
MRA	RCA	130.6 ± 6.9	3.0 ± 0.0	2.7 ± 0.5	1.8 ± 1.5
MRA	LAD	103.4 ± 18.0	2.5 ± 0.5	2.2 ± 1.5	1.5 ± 1.2
CTA	RCA	160.1 ± 20.4	4.0 ± 0.0	3.7 ± 0.8	3.8 ± 0.4
CTA	LAD	127.2 ± 38.0	4.0 ± 0.0	4.0 ± 0.0	3.8 ± 0.4

Table 1: Results of the quantitative and qualitative assessment of image quality on 6 patient datasets, where corresponding volumes from both modalities were available.

RESULTS and DISCUSSION – CMRA imaging was successful in all cases and required 6.8±2.8 min, at an average navigator acceptance rate of 39.3±15.8%. Online iterative reconstruction was completed after approximately 2 min. One dataset was excluded from this study, because the overall image quality was corrupted by inhomogeneous T2 preparation due to an incorrectly placed shimming volume. Figure 1 exemplarily shows the reformatted images of the RCA and LAD for one patient with a side-by-side comparison to the corresponding CTA images. Table 1 summarizes the quantitative assessment of image quality for all segments in the cases where images of both modalities were available. In all 14 MR datasets, an average vessel length of 115.3±30.8 mm (RCA) and 108.6±37.8 mm (LAD) was measured, which indicates that this method is robustly capable to depict the coronary vessels over a long range. Nevertheless, an extensive evaluation in larger patient cohorts would be desirable. On average, the outline of the coronary arteries in the proximal and mid segments was sufficiently depicted to allow their segmentation. However, the higher resolution and signal-to-noise ratio in the CTA datasets facilitate a detection of the coronary arteries over a significantly increased length compared to CMRA ($p<0.01$). Furthermore, the high isotropic resolution of whole-heart CMRA also allows exact aortic measurements and is beneficial for the diagnosis of complex congenital diseases.

CONCLUSIONS – This preliminary study shows that highly accelerated data acquisition enables whole-heart CMRA with high resolution in clinically relevant acquisition times that even allows an integration of the protocol between perfusion and the delayed-enhancement scan. Even though the image quality of CMRA was significantly below the quality of CTA, CMRA provides a promising radiation-free method to visualize congenital malformations. A screening method for coronary artery anomalies to assess the risk of sudden cardiac death [9] could be one potential application of whole-heart CMRA in the future.

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