Volumetric Ultra-Short Breathhold Coronary MR Angiography Using SSFP and Parallel Imaging

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Purpose

Coronary MRA has been proven to be of profound clinical value for the detection of coronary artery disease but remains technically challenging due to physiological motion (1,2). This study is aimed at the development of robust targeted volume acquisition strategies that afford very short breath-hold times of 10-15 seconds and short acquisition windows within the cardiac cycle, with the goal (**i**) to enhance the image quality by minimizing the impact of cardiac and respiratory motion and (**ii**) to improve patient compliance. For this purpose an ECG gated, fat suppressed 3D steady state free precession (SSFP) technique was combined with sensitivity encoded parallel imaging (3,4).

Materials and Methods

3D SSFP was combined with two parallel imaging acquisition schemes:

1 R-R interval approach: Data acquisition is completed in a single heartbeat for each slice partition S_i (Fig. 1a). For *n* slice partitions, the total scan time is equivalent to *n* cardiac intervals instead of 2 x *n* R-R intervals used in the non-accelerated version, which results in ultra short breath-hold periods (t_{BH}=10 s).

2 R-R interval approach: Data acquisition for each slice partition is segmented ($S_{i,1}$, $S_{i,2}$) and distributed over 2 consecutive cardiac cycles. The acquisition window length (t_{ACQ}) is reduced by the acceleration factor for each R-R interval (Fig. 1b) so that it fits into the mid-diastolic cardiac rest period even for high heart rates. The total scan time corresponds to 2 x *n* R-R intervals and is not prolonged compared to the non-accelerated case.

For comparison a conventional, non-accelerated approach, which employed variable sampling in time (VAST) segmentation, was applied (5). An acceleration factor of 2-4 was applied for parallel imaging. A 256x256 data matrix, FOV=31 cm and a slice thickness of 2 mm was used resulting in an interpolated pixel size of (0.6x0.6x1.0) mm^3. No contrast media were administered. CMRA was performed in 17 volunteers. All experiments were conducted on a 1.5T EXCITE TwinSpeed system (GE Medical Systems, Waukesha, WI, USA) using 8-element cardiac phased array coils (GE Medical Systems, Waukesha, WI, USA). Three independent observers scored the images using the following criteria: **1** – coronary artery barely seen, smeared and noisy, **2** – coronary artery visible but low confidence for diagnosis, **3** – the origin and proximal segment are adequately visualized and diagnostic but blurring occurs in the more distal segments, **4** – the origin and proximal segment are very well visualized and the more distal segments are very well depicted. The Mann-Whitney test was used for non-parametric independent two-group comparisons between the conventional and each parallel imaging approach in order to determine statistical significance.

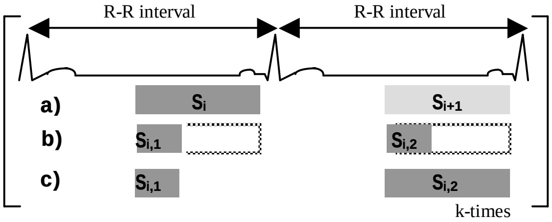

Fig. 1: Basic scheme of the used parallel imaging acquisition strategies: **a)** 1 R-R interval approach, **b)** 2 R-R interval approach. The conventional approach is illustrated in **c)**.

Results

For both parallel imaging acquisition strategies high CNR and SNR images were obtained for the right and left coronary arterial systems as demonstrated in Fig. 2. The overall image quality was rated with a mean of 3.35 (SD=0.6) for the 2 R-R interval approach and 3.39 (SD=0.6) for the 1 R-R interval approach. For comparison the non-accelerated, conventional approach yielded a mean of 2.64 (SD=0.9). The application of the 1R-R interval strategy substantially improved the vessel definition as compared to the conventional approach (Fig. 2a,b). The 1 R-R interval approach halves the breath-hold time (10 sec for a heart rate of 60 bpm). This leads to reduction in blurring artifacts (Fig. 2b), which are associated with the diaphragmatic drift encountered during prolonged breath-holds. No extra cardiac motion sensitivity related blurring was introduced since the acquisition window length was identical to that used in the non-accelerated approach due to the decimation of phase encoding steps. The mean image scores for the 1 R-R interval approach (3.39 $\pm$0.6) are superior to that of the non-accelerated approach (2.64 $\pm$0.9). At high heart rates, the application of the 2 R-R interval strategy eliminated the need to shift the acquisition window towards systole in order to complete the acquisition before the advent of the next R-wave. The shortening of the acquisition window fosters the reduction of cardiac motion artifacts compared to the non-accelerated approach (Fig. 2c,d). This resulted in an image quality, which is superior to that of the non-accelerated approach (p=0.0007) especially for the right coronary artery because of its more extreme extent of displacement. The mean image score for the 2 R-R parallel imaging approach was 3.35 $\pm$ 0.6

Conclusions

It has been demonstrated that the proposed ultra-short breath-hold 3D acquisition strategies result in coronary artery images of high quality. The 1 R-R interval approach is especially applicable at low heart rates. It is tailored to accommodate short breath-holds, which improved image quality and patient comfort. The 2 R-R interval approach is customized for high heart rates. This makes minimizes cardiac contraction related artifacts and helps to overcome acquisition problems associated with arrhythmia. In summary, the application of 3D SSFP combined with parallel imaging permits imaging of all major coronary artery distributions in 2-3 breath-holds. The substantial scan time reduction compared to free-breathing techniques offers the potential to integrate CMRA into a comprehensive cardiac examination for the detection of ischemic or congenital heart disease.

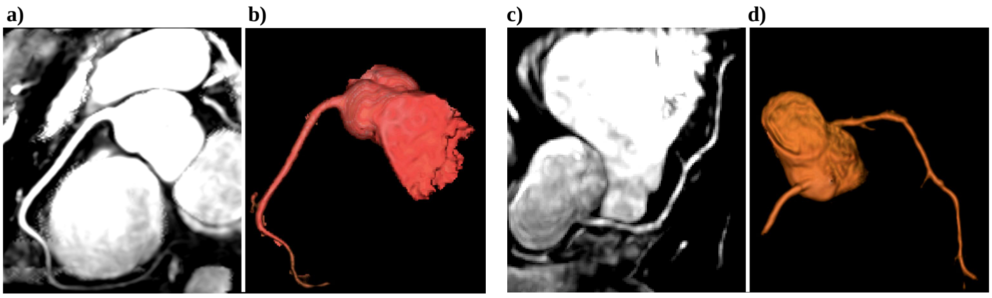

Fig.2: MR angiographies (curved reformatted MIP, slice thickness = 3mm) derived from two different healthy volunteers depicting **a**) the right coronary artery and **c**) the left main and left anterior descending coronary artery. For **a**) the 1 R-R interval parallel imaging approach (matrix size of 256x256, 12 slices) was used resulting in a short breathhold time of only 12 sec. The 2 R-R interval parallel imaging approach was used for **c**). 3D volume rendered views (**b,d**), obtained from the same data sets shown in **a**) and **c**) manifest the robustness of the used acquisition strategies and illustrate the integrity of the raw images.

Fig. 3: RCA images of healthy volunteers exhibiting a heart rate of 55 bpm (**a,b**) and 80 bpm (**c,d**) using **a**) the conventional sampling (t_{BH}=25 s), **b**) the 1 R-R interval parallel imaging approach (t_{BH}=12 s), **c**) the conventional scheme (t_{ACQ}=336 ms) and **d**) the 2 R-R interval parallel imaging approach (t_{ACQ}=120 ms). Note the substantial improvement in the delineation of the RCA at the region of genu (**b**) when reducing the breath-hold time. Reduction in cardiac motion artifacts and improved depiction of the RCA was noted with the shorter acquisition window used in the 2 R-R interval parallel imaging approach **d**).

References: 1) Kim, W.Y. et al., N. Engl. J. Med., 345, 1863-9 (2001), **2)** Bunce N.H. et al., Radiology , 227, 201-8(2003), **3)** Pruessmann K.P. et al., Magn Reson Med, 42, 952-962 (1999)., **4)** King K.F. et al., ISMRM,153 (2000), **5)** Foo. T.K. et al., ISMRM, 1642 (2002)