Accelerated Whole-Heart Coronary Imaging using Multiple Breath-holds and Compressed Sensing Monitored by Self-navigation

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INTRODUCTION – Current research in the field of whole-heart coronary MR imaging is driven by the requirement to significantly reduce the total scan time. In this context, acceleration of the data acquisition with parallel imaging [1] or compressed sensing [2] was recently proposed for conventional navigator-gated examinations. In addition, self-navigation [3, 4] has promised to overcome the fundamental restrictions with regards to scan time efficiency of navigator-gating. Up to now, 1D self-navigation was applied only to 3D radial imaging, since in this case the respiratory offset can directly be extracted from the data. Furthermore, respiratory motion artifacts in free breathing are avoided with radial imaging. In contrast to this, Cartesian data acquisition is superior with respect to the signal to noise ratio (SNR) [5] and is less sensitive to imperfections of the scanner hardware, e.g. gradient delays [6]. Moreover, radial sampling requires a gridding reconstruction, which is the most time consuming factor in an iterative reconstruction. In the present work, a novel incoherent sampling pattern, which features self-navigation properties, is introduced to 3D Cartesian imaging. Undersampled high-resolution whole-heart coronary MRI was performed on four healthy volunteers. Data acquisition was segmented in multiple breath-holds and was combined during iterative image reconstruction utilizing self-navigation. The results were individually compared to free-breathing navigator-gated acquisitions.

MATERIALS and METHODS – Most recently, a spiral phyllotaxis pattern was introduced to self-navigating 3D radial MRI [7]. In the current work, this sampling pattern was generalized to incoherent sampling in the kx-ky phase encoding plane for 3D Cartesian imaging. In case of sagittal slice orientation, the self-navigation properties of an additional SI projection in the sampling pattern can be used to correct for a 1D respiratory offset during image reconstruction. While ECG triggering was performed to avoid cardiac motion, residual respiratory motion artifacts were reduced by segmenting the data acquisition in multiple breath-holds. In addition, a real-time supervision of the respiratory phase was provided during data acquisition.

Further reduction of the total scan time was achieved by significantly sub-sampling the data. In the current work, incoherently sampled data acquired on the Cartesian grid were reconstructed with total variation (TV) regularized, iterative SENSE [6] algorithm. The image reconstruction algorithm was completely integrated into the software architecture of the scanner and features multi-threading for independent phase encoding planes.

In-vivo experiments were performed on four healthy volunteers on a 1.5T clinical MRI scanner (MAGNETOM Aera, Siemens AG, Healthcare Sector, Erlangen, Germany). 3D volume-selective, T2 prepared, fat saturated, ECG-gated, balanced SSFP imaging was performed with the following parameters: TR/TE 4.0/2.0 ms, $\alpha = 90°$, FOV 270x270x150 mm^3, matrix 256x256x144, voxel-size 1.05 mm^3 and a receiver bandwidth of 849 Hz/Px. Signal reception was performed using an 18 channel body array coil and 8 elements of a spine array coil. A total of 5580 readouts were acquired within 8 breath-holds (net acceleration 7). The proposed method was compared to a navigator-gated acquisition with an acceptance window of 5 mm placed in end-inspiration.

The datasets were reformatted using CoronaViz (Work in Progress software, Siemens Corporate Research, Princeton, NJ, USA). For evaluation, image quality was quantitatively measured by computing vessel sharpness of the RCAs and LADs according to [8].

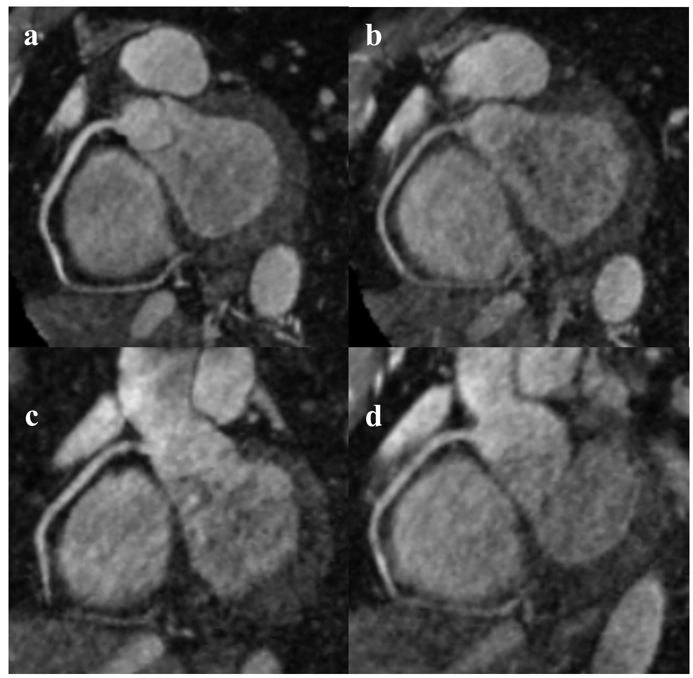

Figure 1: Reformatted images of the RCA acquired with multiple breath-holds (a, c) and navigator-gated protocol (b, d). While the maximal detected respiratory offset with data acquired in multiple breath-holds (a) was lower than the navigator's acceptance window (b), it was greater in (c) compared to the data acquired with navigator-gating (d).

RESULTS and DISCUSSION – Acquisition with multiple breath-holds as well as navigator-gating was successful in all volunteers. The reconstructed images of two subjects for both methods are shown in Figure 1. Reconstruction for each 3D dataset required 2 min. Effective acquisition time was reduced from 7.9±1.0 min for navigator-gating to 2.6±0.2 min using multiple breath-holds. Visual inspection of both breath-hold and navigator-gated datasets resulted in a comparable image quality. Vessel sharpness was measured with 0.33±0.06 (RCA) and 0.34±0.03 (LAD) for the multi-breath hold approach, compared to a sharpness of 0.32±0.07 (RCA) and 0.28±0.02 (LAD) using the navigator. In three of the four volunteers the measured maximal detected offset within multiple breath-holds was below the navigator's acceptance window. Thus, similar results with the proposed method and navigator-gated acquisition were achieved. Series of acquisitions with multiple breath-holds featuring a detected offset less than the acceptance window resulted in better image quality compared to the result of the navigator-gated protocol (see Figure 1a, maximal offset 1 mm). On the other hand, a detected offset (6 mm) within breath-holds greater than the acceptance window increased the effects of respiratory motion, which lead to a reduced sharpness of the coronary vessel as illustrated in Figure 1c.

CONCLUSIONS – The proposed combination of the data acquisition in multiple breath-holds with 1D registration of consecutive datasets proofed to significantly reduce the total scan time compared to conventional navigator gating. Furthermore, iterative image reconstruction allowed for high acceleration factors. In the future, the real-time supervision of the respiratory phase can potentially be used to avoid misregistration of consecutive acquisitions. The robustness of the method and the image quality achieved justifies further investigation in volunteers and patients.

REFERENCES – [1] Weber, O.M. et al., MRM 50:1223-1228, (2003); [2] Moghari, M.H. et al., 18th ISMRM, p. 1247 (2010); [3] Stehning, C. et al., MRM, 51:476-480, (2005); [4] Piccini, D. et al, MRM, in press, (2011); [5] Pipe, J. et al., MRM, 34:170-178, (1995) [6] Block, T. et al, Proc. 19th ISMRM, p. 2816, (2011); [7] Piccini, D. et al, Proc. 19th ISMRM, p. 1259, (2011); [8] Li, D. et al., Radiology, 219:270-277, (2001)

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