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Novel Projection-based Unsupervised Respiratory Motion Feedback for Free-Breathing Whole-Heart Coronary MR Imaging

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INTRODUCTION –Respiratory motion remains a major challenge for whole-heart coronary MR imaging. Lately, self-navigation methods have been proposed [1, 2] which promise to overcome the reduced scan time efficiency of conventional navigator gating. The experience of an extended number of volunteer experiments and initial results in patients revealed that the respiratory motion detection can be degraded by several factors, e.g. suboptimal fat saturation. In particular, if Cartesian sampling schemes are used for acquisition, the suboptimal robustness of such technique can heavily affect the final image quality. However, if the paradigm to correct for motion directly from the feedback of projections acquired in superior-inferior (SI) direction in k-space is left behind, then it seems to be possible to provide a much more robust method to support free-breathing whole-heart coronary MR imaging. Therefore, a new two-stage approach to achieve a binning of the input data in multiple breathing phases is presented. The proposed approach was implemented for free-breathing whole-heart coronary MR imaging featuring a weighted compressed sensing (CS) image reconstruction [3]. The robustness of the new approach compared to the method described in [2] was demonstrated in experiments with 10 healthy volunteers. Furthermore, the correlation to conventional navigator-gated acquisitions was investigated.

MATERIALS and METHODS – If the objective of the tracking in the SI projections is not the correction of the detected motion, but only a binning, then a robust binning procedure can utilize the following observations: 1) The signal variation of SI projections which were acquired at the same respiratory phase within the breathing cycle is very small, 2) if the global variations are minimal this is also valid for any sub-interval within the SI projections. Therefore, the proposed binning procedure first tries to minimize the signal variations in intervals of the SI projections which have high signal variations over time (Fig. 1a). For this purpose, the cross correlation of the signal of each time point to a reference signal is calculated in any such interval (Fig. 1b). Then, the SI projections are binned according to these detected offsets. This is performed with the results of each interval independently. After this, the global signal variation is calculated for each of the bins. Finally, the optimal solution is identified by the minimal accumulated variation of all bins with respect to a single interval. This information can not be used to directly correct for motion but serves as input to the weighted CS reconstruction described in [3].

This method was implemented on a 1.5 T clinical MR scanner (MAGNETOM Aera, Siemens AG, Healthcare Sector, Erlangen, Germany) with software version D13A. Free-breathing whole-heart coronary MRI was performed in 10 healthy volunteers and the proposed method was compared to the approach described in [2]. 3-D 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 270×270×150 mm^3, matrix 256×256×144, 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. The data acquisition was segmented over 398 heart-beats. Within each heart-beat one SI projection was acquired prior to 30 readouts used for imaging. The detected respiratory offset of the proposed method was compared to the result of a simultaneously acquired navigator. For evaluation, the correlation of both signals was estimated.

RESULTS and DISCUSSION – The original method [2] completely failed in 6 out of 10 volunteers which lead to serious artifacts in the images. Using the same datasets, the proposed method successfully identified in all cases an appropriate interval in the SI projection for the detection of the respiratory phases. For this method, the detected offset had an average correlation of 0.955±0.019 to the navigator reference. The synchrony of both methods is shown in a joined histogram exemplarily for one volunteer. This volunteer provides also an example where the resulting reconstruction suffers from residual artifacts by tracking the heart position (see Figure 3a). The new method succeeded to avoid motion artifacts in the weighted CS reconstruction (see Figure 3b).

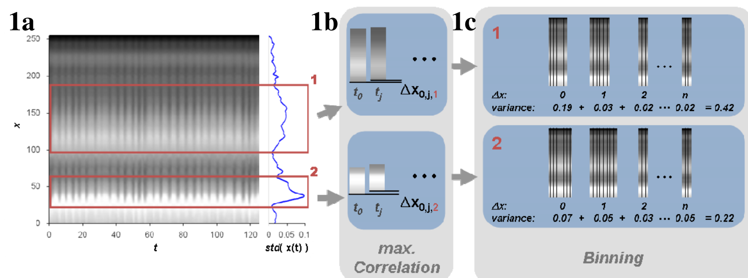

Figure 1: Diagram of the novel binning procedure: First, the correlation of signals is maximized in multiple intervals. Then, the SI projections are binned accordingly. Finally, the interval with lowest intra-bin variance provides the most robust solution.

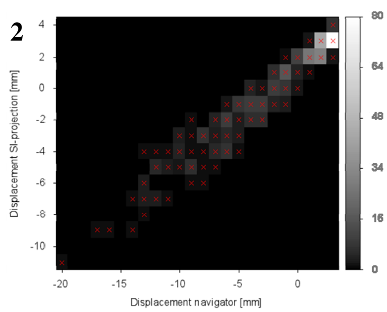

Figure 2: Joined histogram showing the correlation of the proposed method and the conventional navigator. Red crosses denote the occurrences of value pairs.

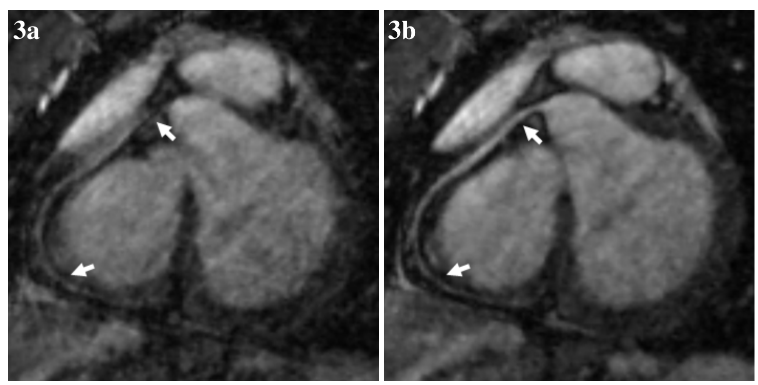

Figure 3: The resulting reformatted images of the RCA from the weighted CS reconstruction based on the (a) estimated offset of the heart and (b) the proposed method as input for self-weighting to one respiratory phase.

CONCLUSIONS – The presented method proved to be a more robust alternative for binning free-breathing whole-heart MRI input data. Although the current results in volunteers are very promising, a comprehensive evaluation in patients with different pathologies is highly desired. Since the current solution was completely integrated in the scanner software, there are basically only very little restrictions in translating this into a clinical prototype. Last but not least, the novel binning approach is independent of any specific MR signal preparation. Thus, other applications like e.g. 3-D CINE MRI might be supported equally well.

REFERENCES – [1] Stehning, C. et al., MRM, 51:476-480, (2005); [2] Piccini, D. et al, MRM, 68:571-579, (2012); [3] Forman, C. et al, Proc 20th ISMRM, p.1160 (2012);

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