Time-Resolved Contrast-Enhanced Coronary MRA with HYPR PR: A Feasibility Study

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Introduction:
Contrast-enhanced MRA is a promising technique for coronary artery imaging. Contrast agents are used to improve the coronary blood signal intensity and blood-myocardial contrast. However, the blood signal changes during the contrast injection time will result in image artifacts, blurring and relatively low SNR, when the *k*-space segments from different cardiac cycles are combined to reconstruct the final image as "time-averaged". Thus, it is important to acquire data during maximal blood signal enhancement for first-pass, contrast-enhanced MRA, and relatively high temporal resolution is required. Time-resolved data acquisition with Highly Constrained Backprojection reconstruction (HYPR) has been proposed to reduce streak artifacts and increase CNR, permitting decreased numbers of projections for each image acquisition in the image time series [1]. In this work, we investigated the feasibility of HYPR reconstruction with 2D PR for time-resolved contrast-enhanced coronary MRA.

Methods:
Simulations: A 2D computer model was created to demonstrate the artifacts caused by blood signal changes, and the suppression of these artifacts by HYPR processing. Acquisition of undersampled interleaved *k*-spaces with varying blood signal was simulated, and the HYPR images at the blood signal peak were compared with the corresponding composite images.
In vivo Studies: Six healthy volunteers were scanned on a 1.5T scanner (Sonata, Siemens, Erlangen, Germany). Contrast-enhanced images were acquired during the first-pass of the contrast agent within a single breath-hold. 6 ml of contrast material, chased by 9 ml of saline solution, was injected at a rate of 3 ml/s. An ECG-triggered, 2D FLASH (fast low angle shot) sequence with radial *k*-space sampling was used with the following parameters: TR/TE/flip-angle = 5.02/2.51/20º, FOV = 300×300 mm^2, matrix = 256×256, slice thickness = 4 mm. The 2D *k*-space was acquired in an interleaved fashion with 16 projections per heartbeat over continuous 16 cardiac cycles, as shown in Figure 1. HYPR method was used to reconstruct time-resolved images (one image per cardiac cycle) combining signal intensity information from the undersampled radial projections, and the structural information from the composite image. The 2D MRA images were acquired targeting the left anterior descending (LAD) or right coronary artery (RCA). Blood-myocardial CNR (mean blood and myocardium signal intensity difference divided by the standard deviation (SD) of the background noise signal [1]) of the aorta at the level of the LAD or RCA were measured across the entire series of HYPR images, and compared to that in the composite images.

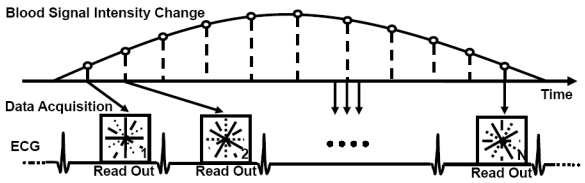

Figure 1. Schematic of the segmented 2D radial *k*-space acquisition, with highly undersampled, interleaved, and equally spaced projections per cardiac cycle. Blood signal intensity varies in different cardiac cycles due to the flow in and out of the contrast agents. Full *k*-space was covered after multiple cardiac cycles and high temporal resolution per cardiac cycle was achieved after HYPR post-process.

Results:
Simulations: As shown in Figure 2, artifacts in the composite images are caused by combining the undersampled data with significantly different signal intensities (a1, b1, c1), which were dramatically suppressed in the time-resolved HYPR images (a2, b2, c2) at simulated signal intensity peak.
In vivo Studies: A full *k*-space based composite image (a) and single frame undersampled images at the blood signal intensity peak without HYPR (b) and with HYPR post-processing (c) from a volunteer during diastole are shown in Fig. 3. *K*-space undersampling caused obvious streaking artifacts and blurring (b), and HYPR image (c) gives much clearer structure with suppressed artifacts based on the same undersampled *k*-space projections. Compared to the composite image (a) by conventional reconstruction method, there were no apparent image artifacts in the HYPR images typically associated with vast undersampling of the PR *k*-space. The artifacts are successfully suppressed with HYPR algorithm. The signal in the region of interest (ROI) of HYPR image at the blood signal intensity peak is increased with similar background signal, and the background noise was suppressed which causes increased CNR in the HYPR image. With HYPR PR, time-resolved 2D coronary artery images were acquired for every cardiac cycle (with 16 radial views), resulting in a temporal resolution increase by a factor of 16 as compared to the conventional PR acquisition. Peak CNR of the coronary artery in the time-resolved HYPR images (53.83 ± 16.89) was improved by 154% as compared to that of the composite image (21.17± 7.4) (p=0.001, paired t-test), despite a data reduction factor of 16 (Figure 4).

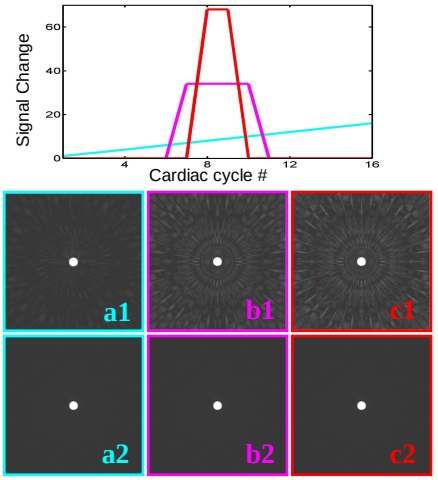

Figure 2. Comparison of the simulation results of composite images and corresponding HYPR images with different signal change scheme: (a1) signal intensity increases from 1 to 16 proportionally, (b1) equal to 34 in 7-10 heartbeats, and 0 for other 12 heartbeats, (c1) equal to 68 in 8-9 heartbeats, and 0 for other 14 heartbeats. The corresponding HYPR images, (a2), (b2), and (c2) at the intensity peak are shown in the second line, with the artifacts were successfully suppressed.

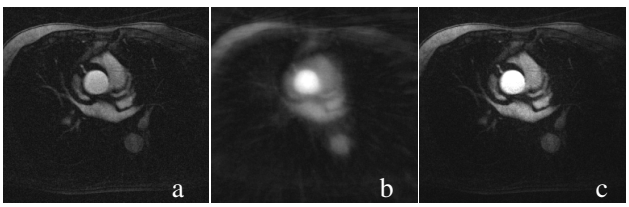

Fig 3. Contrast-enhanced diastolic images acquired with 2D radial MRA method from a healthy volunteer. (a) Composite image based on full k-space. (b) Single frame image at the blood signal intensity peak based on undersampled k-space. (c) HYPR image derived from the same undersampled k-space used for (b).

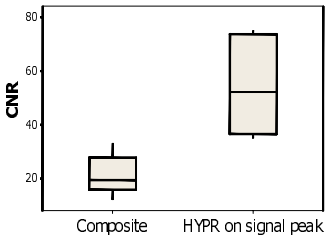

Fig 4. CNR measured from six volunteers. Note the significantly improved blood-myocardial CNR of HYPR images on the blood signal intensity peak.

Discussion and Conclusions:
This work demonstrated the feasibility of HYPR PR for time-resolved, contrast-enhanced coronary MRA. Using this method, the temporal resolution can be increased. In addition, coronary artery images around the time of peak blood signal enhancement have significantly improved CNR and suppressed artifacts over composite images collected with much longer acquisition times and during substantial blood signal changes. Future work will assess the utility of the technique in 3D contrast-enhanced coronary MRA.

References:
1. Mistretta CA, et. al. MRM, 55: 30-40, 2006